TOMASZ BUGALSKI, D.Sc.,N.A.
Polish Academy of Sciences
Institute of Fluid Flow Machinery
Gdańsk
TOMASZ BECH, M.Sc.,N.A.
Ship Design and Research Centre
Gdańsk

BOS-L A Computer System for the Ship Flow Investigation

SUMMARY

The paper contains the analysis and conclusions arising from practical application of the BOS-L computer system to the ship flow investigation. A short description of the computer system and example of calculation are included. The results form the basis for the analysis of possible applications of the BOS-L system as a tool for ship hull design. The conclusions of the paper arise from the comparison of the experimental data and calculation results.

This is a revised and supplemented version of the paper presented at International Conference on Problems of Marine Propulsion HYDRONAV '95, Gdańsk, November 1995.

INTRODUCTION

The work on „the numerical towing tank" has been carried out for several years. Three years ago a four-person group was appointed which has developed a computer system for determination of the potential flow around the ship hull with included free surface effect. During the last year the team has been working to add viscous calculations and propeller interaction effect to the system. The result of that work, the BOS-L computer system, is now intensively tested in IMP-PAN and CTO. Parallelly, the „numerical towing tank" remains under development in the areas of the viscosity modelling methods, automation of panelization process and adjustment of the system to multihull-and fast-ship calculations and design.

DESCRIPTION OF BOS-L COMPUTER SYSTEM

The system is composed of a large number of subroutines organized into ten calculation modules, one data input module and five modules for graphical presentation of the results. All elements of the system are written in FORTRAN. Calculation may be performed on Silicon Graphics Iris Indigo 2 workstation or IBM compatible 486/16Mb RAM PCs.

The case of a surface ship moving with constant velocity and straight course on the initially undisturbed flat water surface is considered. The analysis is performed in the Cartesian system of co-ordinates with Ox axis located in the ship plane of symmetry pointing towards stern, Oy axis pointing to starboard and Oz axis pointing vertically down. The origin of the system lies on the water surface in the middle of the hull length between perpendiculars Lpp. The flow is assumed stationary and irrotational and water incompressible. The water is regarded as unlimited for $z > \zeta$.

The process of solution starts from the analysis of flow around a „double" hull, assuming that the free water surface is a rigid flat wall.

The velocity potential, Φ described by the expression (1), is generated by a system of Rankine sources distributed on the hull wetted surface S and on the surface of its mirror image.

$$\Phi\left|x,y,z\right| = \iint \frac{\sigma\left|q\right|}{r\left|p,q\right|} dS + n_x \cdot V \qquad (1)$$

The numerical solution starts with discretization of the hull wetted surface which is divided into a grid of flat quadrilateral elements.

After the discretization of the surface S, the equation (1) which is the Fredholm equation of the second kind, is converted into a system of linear equations of the following form:

$$\sum_{j=1}^{N} A_{ij}\sigma_j = -n_{xi} \cdot \left| V_s + V_{pi} \right| \qquad (2)$$

where:

n_{xi} - unit length normal vector on the i-th quadrangle
σ_j - source density on the j-th quadrangle
A_{ij} - induction matrix element
V_{pi} - velocity induced by propeler on the i-th quadrangle

The free water surface is defined in the following form:

$$\frac{\partial^2\Phi}{\partial x^2} - \frac{g}{V_s^2} \cdot \frac{\partial\Phi}{\partial z} = 0 \qquad (3)$$

with the corresponding expression of the wave height:

$$\zeta = -\frac{V_s}{g} \cdot \frac{\partial \Phi}{\partial x} \Big|_{z=0} \quad (4)$$

These relations are known from the theory of wave resistance of a ship in deep water.

The free water surface is divided into a number of elements in the manner similar to that applied to the hull surface. The velocity generated in the i-th point on the free water surface by the j-th source on the hull surface may be described as:

$$V_{xi} = \sum V_{xij} \sigma_j \quad (5)$$

The geometry of the Bernoulli wave system is defined as follows:

$$\zeta_i = -\frac{V_s}{g} V_{xi} \Big|_{z=0} \quad (6)$$

It describes the displacement of the water surface caused by the system of sources modelling the ship hull.

The system of ship-generated waves is obtained through a transformation of the Bernoulli waves. The transformation is based on an original solution of the Green function for a single moving pressure pulse [5] and original method of superposition of such solutions leading to a very short computation time.

Then the potential flow streamlines on hull surface are determined with the influence of free surface taken into consideration. The parameters of boundary layer on the hull surface are calculated along those streamlines with the help of integral methods (Truckenbrodt method among others). The parameters enable to determine the velocity field inside the boundary layer and its thickness distribution.

As the dimensions of the hull are increased by displacement layer thickness the flow around such calculated hull shape is determined again. The velocity field on the hull surface is appropriately modified, if calculations are connected with consideration of operating screw propeller.

The flow parameters are finally determined by using an iterative process in which the equivalence of propeller thrust and hull drag is the convergence condition.

The additional calculations behind the stern with the use of RANS procedure are carried out for better estimation of velocity field in propeller neighbourhood.

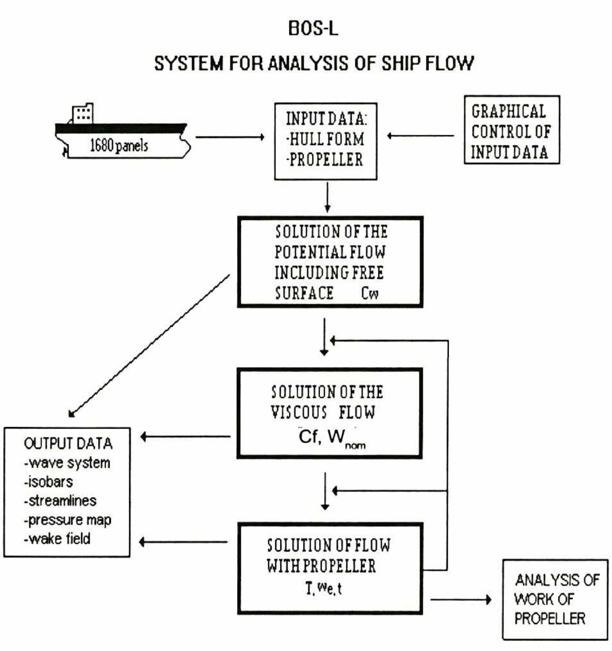


Fig. 1. Block diagram of the BOS-L system.

PRINCIPLES OF APPLICATION OF BOS-L SYSTEM

The results of calculation performed with the use of BOS-L system contain the following information:

- streamlines on the hull surface
- static pressure distribution on the hull
- wave profile along the waterline
- wave system on the free surface
- wake field at propeller plane
- values of the wave and viscous resistance.

Such results are helpful for an preliminary analysis of ship hydrodynamic properties.

This analysis yields the groups of information given in Fig. 2 (see page 9 and 10).

EXAMPLES OF PRACTICAL APPLICATION OF BOS-L SYSTEM

The BOS-L system has been carefully tested after each step of its development. Each time the calculations were performed for the following hulls: Wigley's model, Series 60 ship model (foreign data set), 409 container, 416 and 424 bulk carriers.

Quite a good agreement between theoretical predictions and model test data for Wigley's model and S60 was obtained. Apart from the standard resistance and propulsion experiments the additional measurements and tests were performed for the 409, 416 and 424 ships in order to obtain: the pressure distribution on the hull surface, wave profile, wave pattern and shape of streamlines. The agreement between test results and computer predictions was quite satisfactory also for those models. Additionally, it was observed that:

- hull drag value depends strongly on the panelization quality
- the drag value is comparable with numerical errors of the method [1, 2] especially at low Froude numbers.

The rules of correct panelization were investigated in successive series of calculations and measurements performed for several modifications of three similar container ships. The influence of relatively small variations of hull shape on the calculation results was examined. The rules of panelization, coefficients of panelization quality (and their relations to hull drag) were developed on the basis of those results. The results form a valuable base of experience for users of the system (see Tab.).

Practical applications of BOS-L system (IMP-PAN, CTO, Gdańsk Shipyard)

Symbol	Type of ship	Lpp[m]	Fn[-]	Type of calc.*
Wigley	test s.	2.50	0.12-0.50	P,V
S60 Cb=0.6	test s.	4.00	0.16-0.35	P,V
HSVA tanker	test s.	253.00	0.19	P
409	container s.	212.20	0.255	P
416	bulk c.	200.00	0.116-0.186	P
424	bulk c.	240.00	0.19	P
432	container s.	165.20	0.267	P
KT3-9X 6mod	container s.	165.20	0.25-0.28	P
KT10-13X 4mod	container s.	159.70	0.27	P
M1	container s	159.70	0.27	P
KT14X	container s	163.60	0.26-0.27	P
S1	reefer v.	138.50	0.306	V
S2	reefer v.	126.80	0.291	V
S3	bulk c.	181.80	0.179	V
S4	container s.	195.00	0.255	V
S5	container s.	227.80	0.267	V
M2A/M2B	container s.	140.00	0.264	V
M3	container s.	124.00	0.258	V
M4/M4A/M4B	container s.	195.2	0.253	P,V

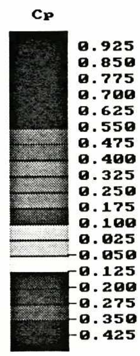
*) P - using potential code, V - using viscous code

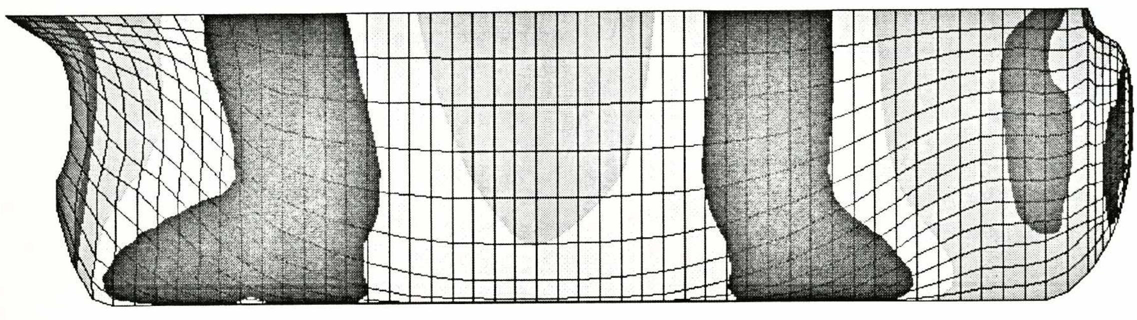
The next step of system development consisted in the verification of viscous calculations. The early analysis included the examination of velocity field in the propeller disc. The discrepancies observed during the early analysis caused that essential corrections of the system, including RANS procedure development, were introduced. The corrections improved the agreement between experimental and numerical results. Efforts are now focussed on the verification of calculation methods suitable for a ship with operating propeller and boundary layer detachment on a hull surface.

Fig. 2. Examples of basic and informative plots available from BOSS-L system
Note: All the plots are for M3 model tested at Fn=0.258 (see Tab.).

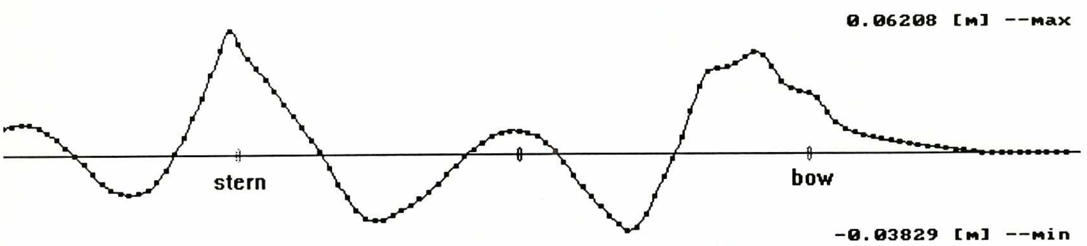
Basic plots:

- plot of pressure distribution on the hull → qualitative assessment of resistance

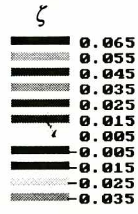


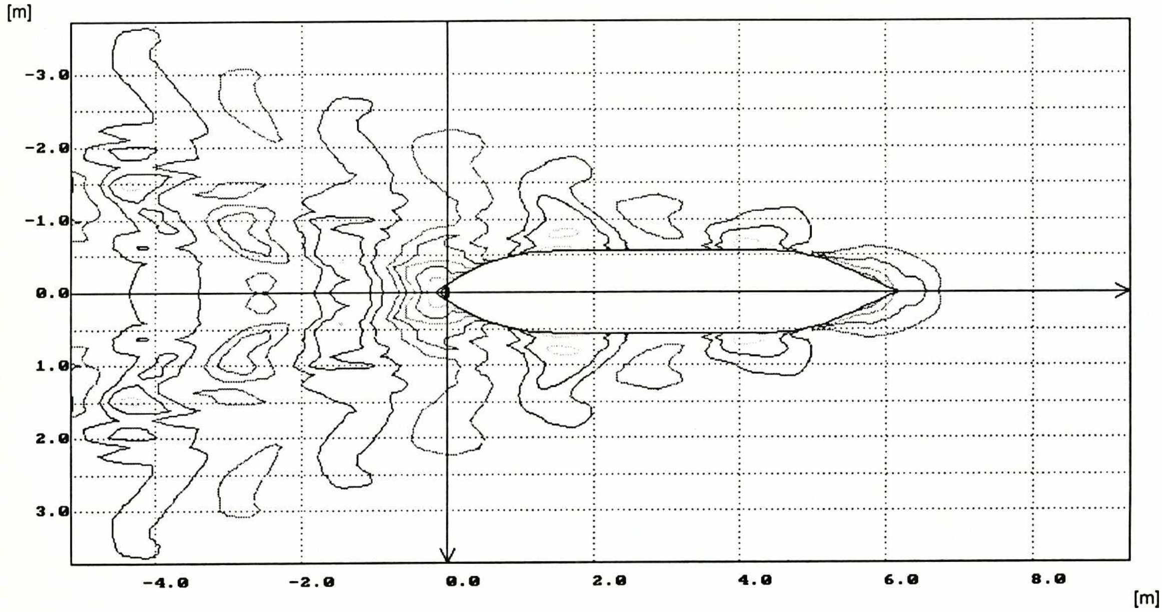


- plot of wave profile along the waterline → qualitative assessment of resistance

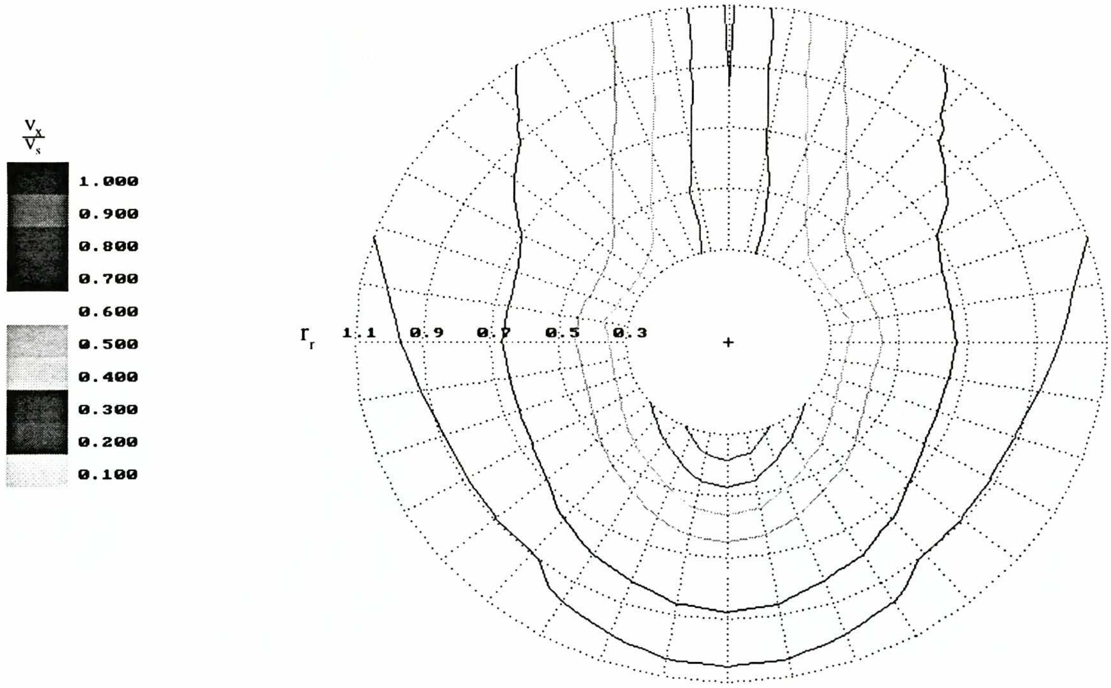


- plot of wave system on the free surface → qualitative assessment of resistance



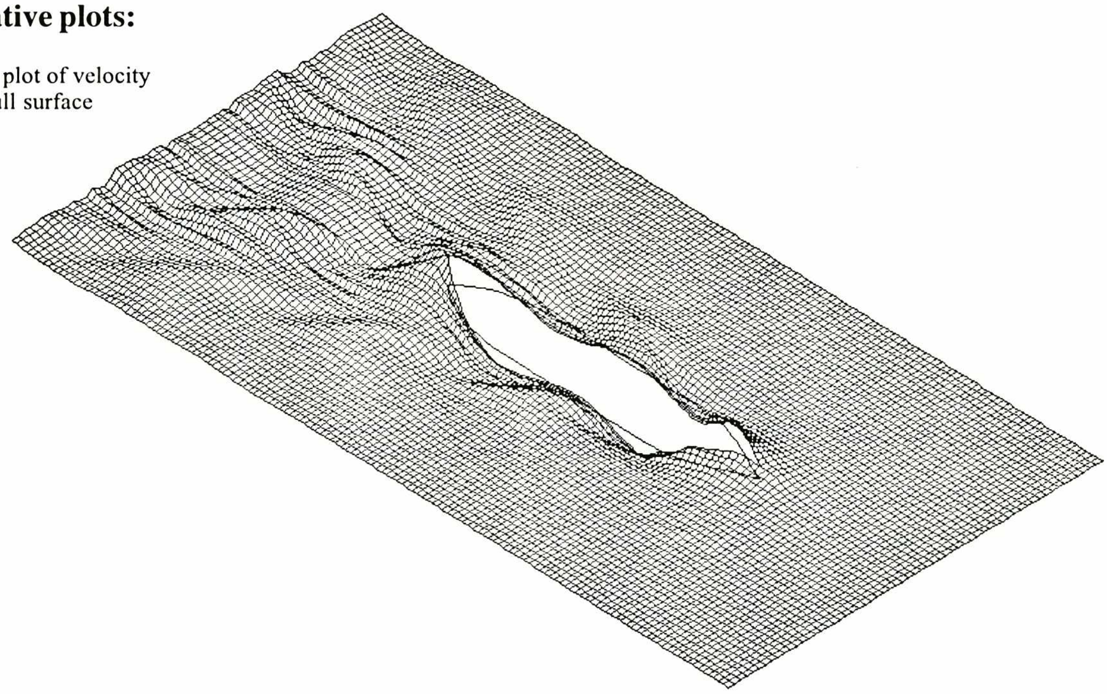


- plot of wake field → for analysis of propeller working condition

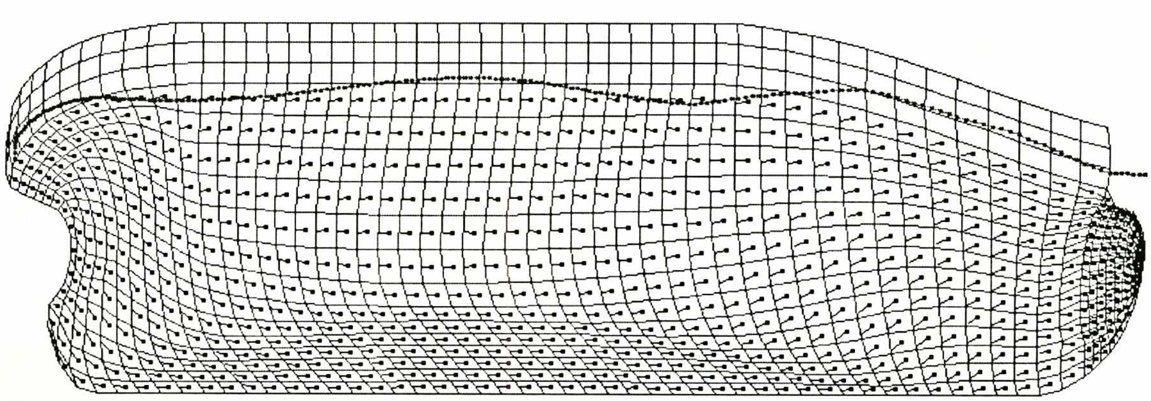


Informative plots:

- vectorial plot of velocity on the hull surface



- plot of perspective views of wave system



THE DIRECTIONS OF SYSTEM DEVELOPMENT

The system is developed in the following directions:

- the maximum available automation of panelization process
- possible accounting for transom stern, multi-hull ships, shallow water conditions in calculations
- the development of boundary layer determination methods, integral methods and RANS.

EXAMPLE OF CALCULATION

For the purpose of BOS-L system presentation the calculations were performed for M4 and M4A models of a modern container ship (L_{pp}=195.25m) [7]. The objective of the analysis was to assess the influence of two variants of the bow bulb geometry on the flow characteristics and on the wave resistance at a given constant Froude number.

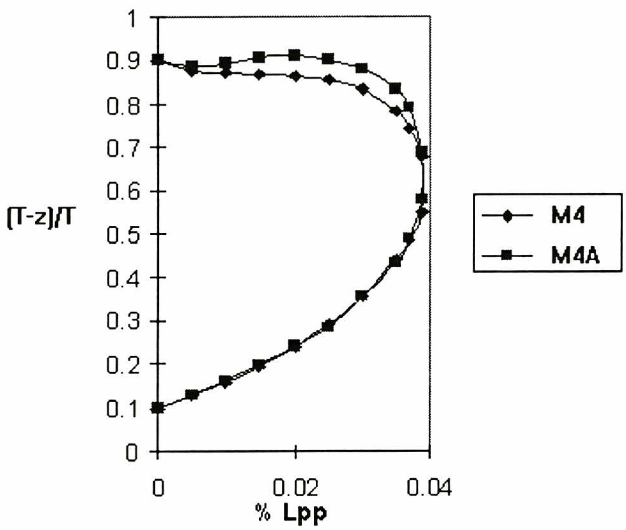


Fig. 3. The bulb profiles

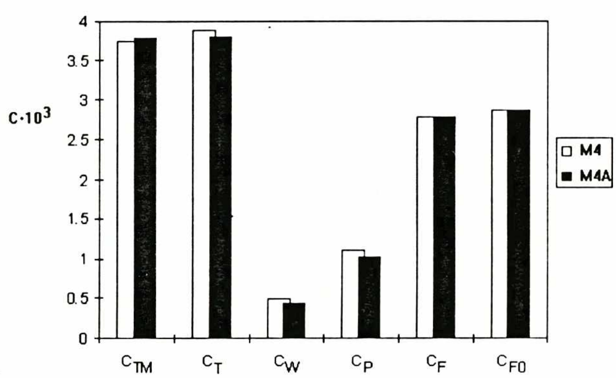


Fig. 4. Comparison of resistance components for the tested ship models with two bulb variants

Fig. 3 shows schematically the analysed bulb profiles. Fig. 4 shows the comparison of resistance components calculated for the two variants of the container ship model. As one would expect, **both variants produced equivalent values of the total, wave, pressure and frictional resistance**. The differences between the calculated and measured values are within the expected error margin.

The tendency shown in Fig. 4 was confirmed by model experiments [7].

The presented results demonstrate that the system can supply useful information about the hydrodynamic quality of different hull forms.

CONCLUSIONS

★ The BOS-L system fulfils the standard requirements for the software applicable to ship flow analysis.

★ The system allows to qualitatively assess the influence of hull shape on its hydodynamic performance.

★ The system is now,after the verification, being applied in the preliminary hull shape assessment.

NOMENCLATURE

A	- induction matrix element
C_f	- frictional resistance coefficient
C_{F0}	- flat plate frictional resistance coefficient
C_p	- pressure resistance coefficient
C_T	- total resistance coefficient, thrust loading coefficient
C_{Tm}	- model total resistance coefficient
C_w	- wave resistance coefficient
F_n	- Froude number
g	- gravity acceleration
i	- number of a panel, number of a point on free water surface
j	- number of a panel, number of a point on hull surface
L_{pp}	- ship length between perpendiculars
n_x	- unit length normal vector
N	- number of elements on the „double" hull
p	- point in space
q	- point on hull surface
r	- distance between p and q points
r_r	- relative propeller radius
S	- hull wetted surface
t	- thrust deduction fraction
T	- propeller thrust, draft
V	- velocity
V_p	- velocity induced by propeller
V_S	- ship velocity
w_e	- effective wake
w_{nom}	- nominal wake
x,y,z	- Cartesian system of co-ordinates
ζ	- wave height
σ	- source density
Φ	- velocity potential
CFD	- Computational Fluid Dynamics
CTO	- Ship Design and Research Centre
IMP-PAN	- Institute of Fluid Flow Machinery, Polish Academy of Sciences
RANS	- Reynolds -Averaged Navier -Stokes equations

BIBLOGRAPHY

1. Bertram V., Jensen G.: „ The Wave Resistance Problem ". 19th WEGEMT School, Nantes, 20-24 September 1993
2. Bertram V., Jensen G.: „Applications and Limitations of Potential Flow Codes for the Wave Making Problem ". 19th WEGEMT School, Nantes, 20-24 September 1993
3. Bugalski T., Koronowicz T., Szantyr J., Waberska G.: „ Computer System for Calculation of Flow, Resistance and Propulsion of a Ship at the Design Stage ". 5th CADMO'94, Southampton, September 1994
4. Bugalski T., Szantyr J.: „ The Design of Hull Form Using Computer System for Analysis of Ship Flow ". 8th ICCAS, Bremen, 5-9 September 1994
5. Koronowicz T.: „ Numerical Solution of the Formula Describing the Waves Generated by a Pressure Impulse on the Free Surface of Water ". IMP-PAN Report 427/1376/94, Gdańsk, 1994 /in Polish/.
6. Proceedings of CFD WORKSHOP TOKYO 1994 - An International Workshop for Improvement of Hull Form Designs, Tokyo, 22-24 March 1994
7. CTO Technical Report RH-95/T-148.

Appraised by Henryk Jarzyna, Prof.,D.Sc.,N.A.