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CTO and SVA joint research project on computation of ship flow phenomena

SUMMARY

The report describes results of Ship Design and Research Centre Gdańsk (CTO, Poland) - Schiffbau Versuchanstalt Potsdam (SVA, Germany) joint research project on computations with the use of BOS-L and SHIPFLOW numerical model basins. The subject of the project was application of CFD methods to studying the phenomena of ship flow.

Results of the flow parameter computations for four different ship models (two from CTO and two from SVA) are presented. Some calculation results are compared with experimental data.

INTRODUCTION

In 1995 the Ship Design and Research Centre (CTO) and Schiffbau Versuchanstalt Potsdam GmbH (SVA) concluded an agreement on carrying out joint research projects in the field of marine hydromechanics. The work described in this paper is a result of the project on „Computational Fluid Dynamics for design of fine ship lines", jointly conducted in 1996. Both model basins selected 4 different ship models : 2 from CTO and 2 from SVA (2 containers, 1 bulk carrier and 1 tanker, see Tab.1). The numerical analysis of flow parameters of the models was performed by using „the numerical model basins": the SHIPFLOW at SVA and BOS-L at CTO. The calculation results were discussed during meetings held in Potsdam in March 1996 and in Gdańsk in August 1996. The results obtained from BOS-L and SHIPFLOW systems were compared to each other and confronted with results of model experiments. Encouraging results of the comparisons and confrontations formed the basis for establishing the directions of further co-operation between CTO and SVA in the field of marine hydromechanics.

BOS-L COMPUTER SYSTEM

The BOS-L system, still under development, was originally elaborated on the basis of the research work [1,2] carried out for several years in Poland. A detail description of the system and first experience from its use was earlier published in this journal [7].

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 workstations or IBM compatible PC's.

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.

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

SHIPFLOW COMPUTER SYSTEM

All SVA calculations of the joint research project were carried out by using the SHIPFLOW system, developed by L. Larsson and his co-workers at Chalmers University of Technology, and FLOWTECH International AB [4]. The SHIPFLOW contains three main modules: Rankine source panel method, boundary layer method and Navier - Stokes method. Since the investigated hulls are slender the viscous flow is computed by using the boundary layer module only, so the Navier - Stokes part is not used. The free - surface boundary conditions are linearized by means of the first order Taylor series expansion. Higher order terms are thus assumed small and neglected. The numerical solution employs a technique where the ship surface and the free-surface are discretized by using flat panels with constant source strength. The system of equations which includes the body and free-surface sources is set up and solved by using a direct solver based on the Gaussian elimination with pivoting. The velocity and pressure are then computed on each panel and the wave height is obtained from the linearized dynamic free - surface boundary condition. The wave resistance is finally computed from pressure integration over the hull surface. The boundary layer is calculated by using 3-D momentum integral equations in the small cross - flow approximation. Solutions are obtained along a set of streamlines traced on the hull, based on the potential flow solution. The output from the boundary layer module is various boundary layer thickness, shape factor and skin friction. The latter is also integrated over the surface to obtain frictional resistance.

COMPARISON OF CALCULATIONS AND EXPERIMENTAL DATA

The main parameters of the ship models selected for the joint research are presented in Tab.1.

In the case of 606, 873 and m409 ships the additional measurements and tests were performed, apart from standard resistance and propulsion experiments, in order to obtain :

- the pressure distribution on the hull surface
- wave pattern, wave profile
- shape of streamlines.

Available experimental results are presented in Tab.2. Special measurements of wave pattern profile were available for m416c (CTO) model only.

The results of calculations and measurements of CTO ship models were discussed during meeting held in Potsdam in March 1996.

The determination accuracy of the resistance components of the container ship m409 (CTO) only was assessed. The results of calculations by using the SHIPFLOW and BOS-L systems agreed well with the results of experiments (Tab.3).

***Tab.1.** Main parameters of models selected for joint research project*

Ship	873 container	606 tanker	m409 container	m416c bulk carrier
Institution	SVA	SVA	CTO	CTO
Lpp [m]	5.100	6.000	6.529	4.000
B [m]	0.794	1.000	0.993	0.644
T [m]	0.300	0.364	0.339	0.250
λ(scale factor)[-]	32.000	31.000	32.500	50.000
C_B [-]	0.620	0.801	0.650	0.800
V [m/s]	1.634	1.534	2.040	1.163
Fn [-]	0.231	0.200	0.255	0.186

***Tab.2.** Available experimental data of four ship models*

Model symbol	Wave pattern or wave profile	Resistance components	Pressure distribution on hull surface	Streamlines on hull surface	Nominal wake
			SVA		
873	●	-	-	●	●
606	●	-	-	●	-
			CTO		
m409	●	●	●	●	●
m416c	●	-	-	-	-

Note: ● *Available experimental data*

When assessing the calculation results of the wave system of both CTO models one may conclude that :

- **for the container ship** : both systems overestimate the height of the stern wave, the SHIPFLOW system markedly underestimates the height of bow wave while the BOS-L system produces relevant results much closer to experiment. The number of waves and system of crests and troughs from both computer systems are similar and they agree well with experiments (Fig.1,2).
- **for the full ship at low Froude number** : both systems produce the wave patterns of similar shape and wave height (Fig.7,8).

***Tab.3.** Comparison of calculations and measurements of resistance and flow parameters of CTO ship models*

	Number of panels on half of hull	Resistance		Wave pattern		10 Maxim. height of bow wave	Wake (w_{nom})
		$10^3 C_R$	$10^3 C_{Tm}$	10 max	10 min		
			m409 (Fn=0.255)				
SVA	564 (8 iter.)	0.527	-	0.53	-0.27	0.35	-
CTO	1183	-	4.110	1.47	-0.47	1.01	0.267
			m409 (Fn=0.243)				
SVA	564 (8 iter.)	0.528	-	0.47	-0.25	0.31	-
CTO	1183	-	3.991	1.26	-0.41	0.846	0.273
			CTO tests : m409				
Fn=0.259		0.681	4.339	1.05	-0.45	1.05	-
Fn=0.248		0.569	4.255	0.85	-0.28	0.85	-
Fn=0.237		0.392	4.107	0.78	-0.24	0.78	0.305
			m416c (Fn=0.186)				
SVA	~500 (3 iter.)	0.821	-	0.584	-0.421	0.58	-
CTO	777	-	4.21	0.690	-0.480	0.69	0.420

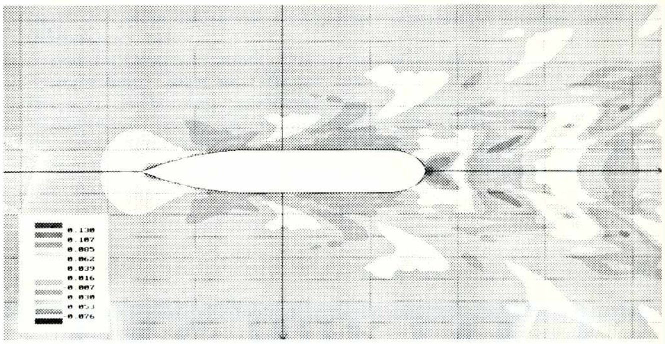


***Fig.1.** Wave pattern calculated by BOS-L (m409, Fn=0.255)*

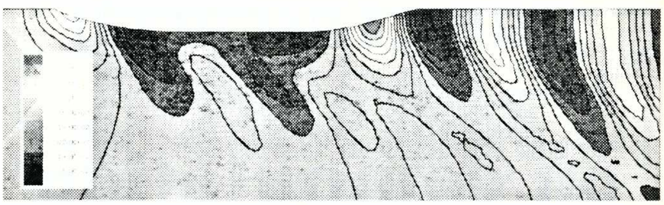


***Fig.2.** Wave pattern calculated by SHIPFLOW (m409, Fn=0.255) (cf. Table 3)*

A comparison of measured and calculated velocity vectors are presented in Fig.3,4 and 5.

- Both systems were unable to predict the separated flow around the non-typical bow bulb of m409 model.
- Both systems made it possible to analyse flow separation phenomena in the stern area only, where the flow was predicted by using RANS method.

The wake distribution predicted by the BOS-L system revealed differences with respect to experiment in the lower region of propeller disc where the calculated iso-wake lines are much more flat than those determined by measurements (Fig.6).

The mean value of the nominal wake w_{nom} is underestimated. However, the quality of the results does not differ from the performance of other such CFD methods as described in the recent ITTC Report [5].

The results of calculations and measurements of SVA models were discussed during the meeting held in Gdańsk in August 1996.

***Tab.4.** Comparison of calculations and measurements of resistance and flow parameters of SVA ship models*

Institution	Number of panels on half of hull	Resistance		Wave pattern		10 Maxim. height of bow wave	Wake (w_{nom})
		$10^3 C_R$	$10^3 C_{Tm}$	10 max	10 min		
			606 (Fn=0.20)				
SVA	-	-	-	0.84	-0.58	0.84	-
CTO	1075	-	4.547	1.32	-0.47	1.32	0.397
SVA test	-	-	-	1.25	-0.50	1.25	-
			873 (Fn=0.231)				
SVA	-	-	-	0.27	-0.20	0.25	-
CTO	1051	-	3.480	0.47	-0.19	0.32	0.263
SVA test	-	-	-	0.80	-0.32	0.8	0.305

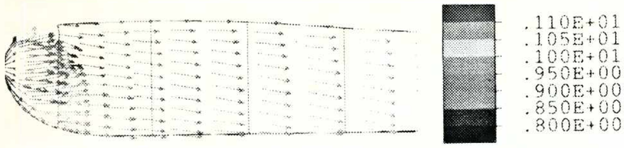


Fig.3. Velocity vector plot calculated by SHIPFLOW (m409, Fn=0.255)

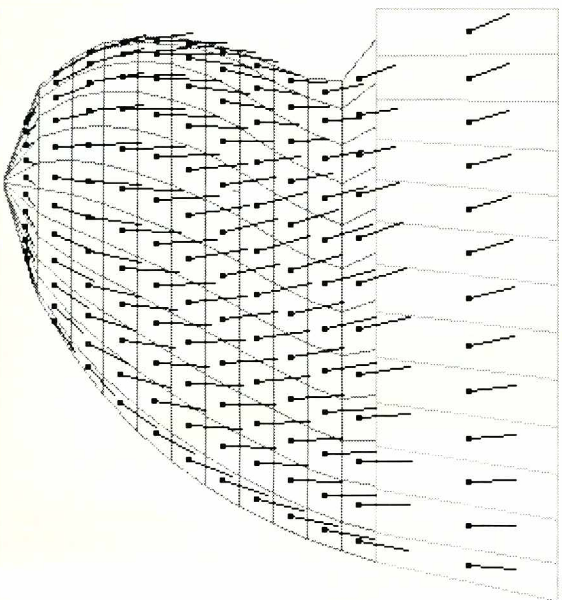


Fig.4. Velocity vector plot calculated by BOS-L (m409, Fn=0.255)

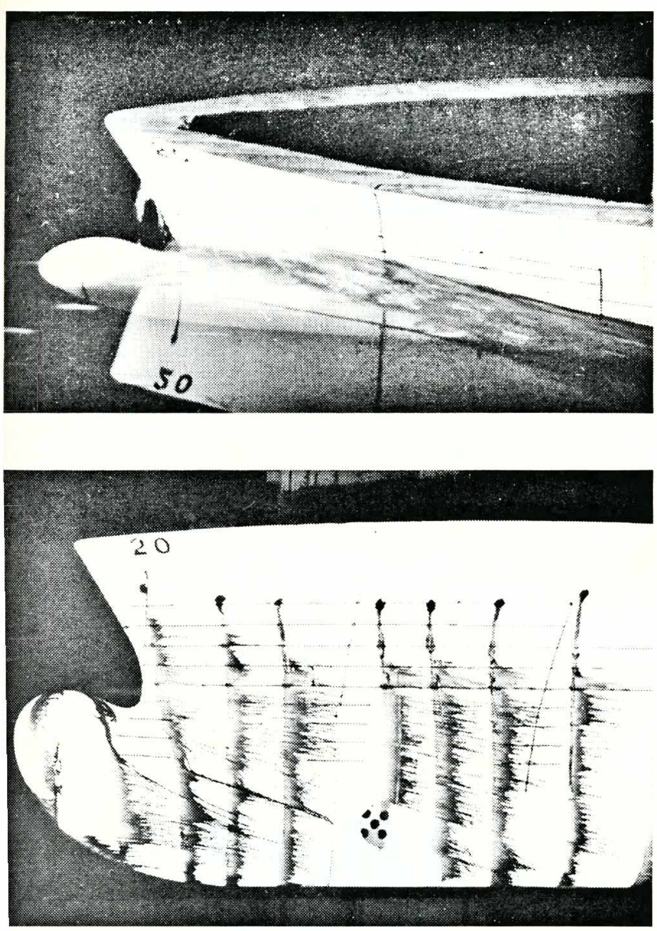
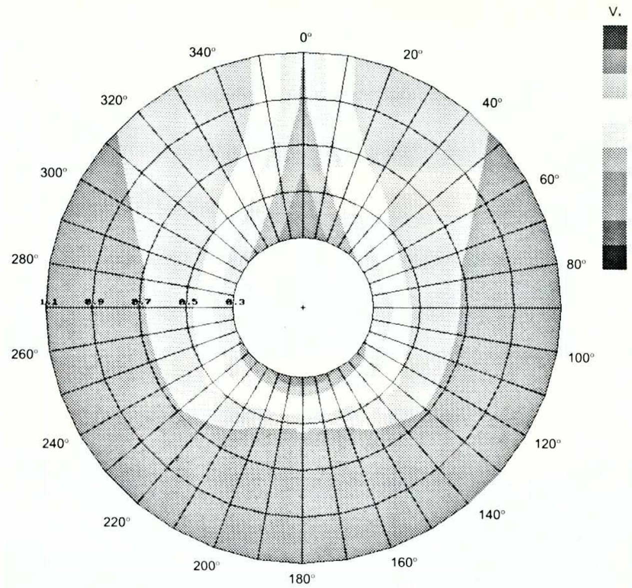


Fig.5. Wave profile and streamlines on bow of m409 model - CTO tests (Fn=0.237).



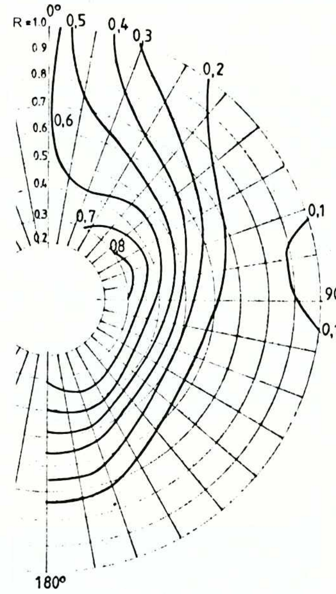


Fig.6. Nondimensional nominal velocity V_x calculated by BOS-L for an 409 model at $F_n = 0.243$ and nominal wake $w_{nom} = 1-V_x$ measured for the same model at $F_n = 0.237$

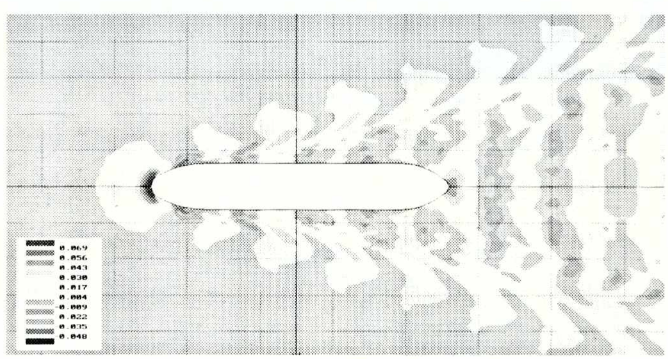


Fig.7. Wave pattern calculated by BOS-L (m416c, Fn=0.186)

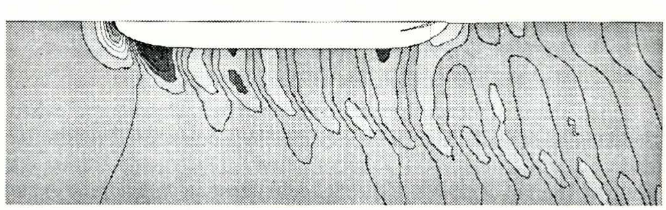


Fig.8. Wave pattern calculated by SHIPFLOW (m416c, Fn=0.186)

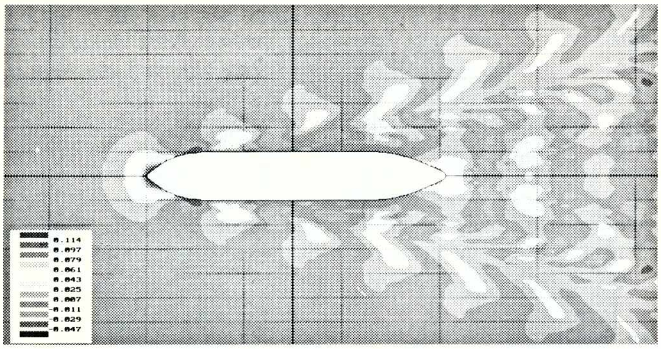


Fig.9. Wave pattern calculated by BOS-L (606, Fn=0.20)

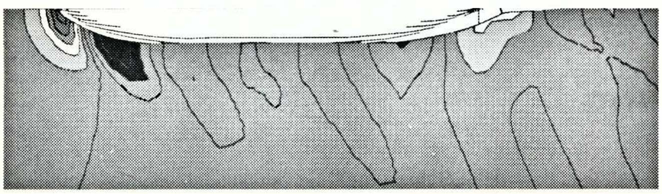


Fig.10. Wave pattern calculated by SHIPFLOW (606, Fn=0.20)

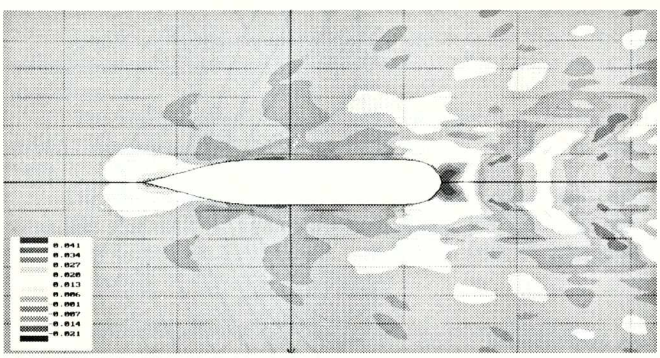


Fig.11. Wave pattern calculated by BOS-L (873, Fn=0.231)

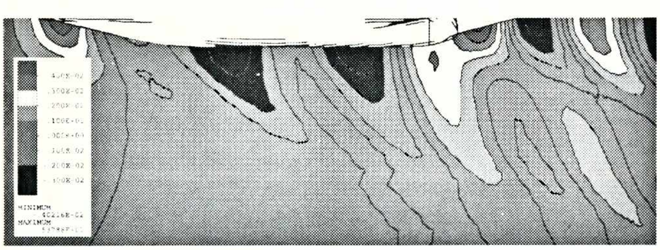


Fig.12. Wave pattern calculated by SHIPFLOW (873, Fn=0.231)

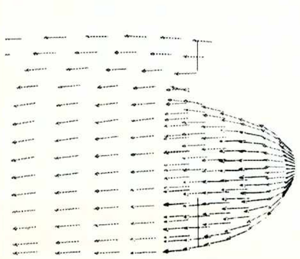


Fig.13. Velocity vector plot calculated by SHIPFLOW (873, Fn=0.231)

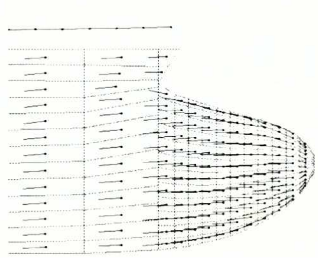


Fig.14. Velocity vector plot calculated by BOS-L (873, Fn=0.231)

The shape of the wave system predicted by both programs, when assessing the calculation results of the SVA models, exhibits similar tendency to that of the CTO models. Both programs determine the shape and height of waves of the tanker in question with similar accuracy and the results agree well with experiment (Fig.9,10).

For the container ship both systems show a markedly underestimated bow wave height while the number and system of crests and troughs agrees well with experiment (Fig.11,12).

The mean value of the nominal wake calculated by using the BOS-L system is underestimated.

The picture of velocity vectors determined by both programs for 873 container ship agrees well with experiment (Fig.13,14).

CONCLUSIONS

The calculation results are satisfactory, especially in view of the performance of similar CFD systems presented during the ITTC 1996 [5], despite certain discrepancies visible in confrontation with experiments. Positive results of the joint research project carried out by CTO and SVA have encouraged both parties to continue the joint work on application of CFD methods in design of ships with high hydrodynamic quality. Since completion of the above described project both CTO and SVA are continuously developing their computer systems with particural attention to :

- numerical system for description of ship hull geometry for the „numerical model basin",
- methods of designing the highly efficient ship hull geometry by means of the „numerical model basin".

Acknowledgments

The authors gratefully acknowledge the support and co-operation of Messrs. K. Rieck (SVA), T. Bech (CTO) and A. Grzonka (CTO) in panelization of models and ship flow calculations.

NOMENCLATURE

- B - breath (beam) of ship hull
- C_B - block coefficient
- C_R - residuary resistance coefficient
- C_{Tm} - total resistance coefficient (of ship model)
- F_n - Froude number
- L_{pp} - length between perpendiculars
- R - nondimensional propeller radius
- T - draft of ship hull
- V - speed of the model or the ship
- V_x - nondimensional axial component of nominal velocity
- w_{nom} - nominal wake fraction
- λ - linear scale of ship model

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