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A Computer Program for Determination of Acoustic Pressure Field Related to Ship Hull and Propeller Operation

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ABSTRACT

The paper presents the results of analysis of the influence of water viscosity and propeller operation effects on the hydroacoustic pressure field generated by the moving ship hull. The analysis is based on the results of calculations using the program based on Computational Fluid Dynamics for the hull flow and lifting surface method for the propeller flow.

INTRODUCTION

The development of the computer program for determination of the acoustic pressure field around the ship hull with operating propeller, financed by the Committee for Scientific Research, has reached its final stage. This has enabled presentation of the results of the analysis of selected factors on the level of hydrodynamic pressure generated by the system hull-propeller.

The computer program CISAKU enables analyses of several different factors influencing the hydrodynamic pressure field around the hull and propeller. The input data to the program consist of hull geometry, propeller geometry, kinematic parameters of motion and parameters characterizing the sea bottom. The results of computations include pressure field defined as isobars located in horizontal or vertical planes in the vicinity of the hull or as pressure variations in arbitrary stationary points located near the hull moving with constant velocity in calm water. These results are supplemented with information about cavitation phenomena present on the propeller blades and about acoustic pressure generated by the cavitating propeller, given in the form of harmonic amplitudes and phase shift angles.

The program calculates the effective non-uniform velocity field at propeller location, thus enabling complete analysis of unsteady operation of the propeller behind ship hull. Consequently, the program may be employed for hydroacoustic analysis of naval and special ships at the design stage, permitting optimisation of the hull and propeller geometry together with their operating parameters from the hydroacoustic point of view. This paper is connected to an earlier paper presented at the XIII Symposium on Hydroacoustics [2], in which the general assumptions of the computational model for prediction of hydroacoustic pressure field generated by the ship hull have been described. In the following sections of this paper the influence of viscosity and propeller operation on the hull-generated hydrodynamic pressure field calculated using that model is presented.

THE INFLUENCE OF VISCOSITY ON THE MAGNITUDE OF THE HYDRODYNAMIC PRESSURE

Experience accumulated during development of the so called numerical model basin [1] has provided ample information about the influence of viscosity on the pressure field generated on the moving ship hull. In this case the effect of viscosity may be sufficiently accounted for through apparent thickenning of the hull by the displacement thickness of the boundary layer. The necessary parameters of the boundary layer may be obtained from the integral relations of von Karman and Leibenson applied along the streamline. In this computer program the algorithm developed by Pei Lin Xian [3] has been employed for this purpose.

The computation is conducted in an iterative way. The starting point is the calculation of the streamlines on the hull in potential, non-viscous flow. In the next step the necessary parameters of the boundary layer, including displacement thickness, are determined along these streamlines. Then the geometry of the hull is modified accordingly and the whole cycle of calculation is repeated. The process of iterations is completed when the relative changes in the boundary layer parameters in the stern region are within 2-3 per cent.

The calculated parameters of the boundary layer in the stern region of the hull, together with the velocity induced by the hull in the potential flow, are used for determination of the non-uniform velocity field at propeller location. This in turn enables calculation of the hydrodynamic characteristics of the propeller and estimation of the velocities induced by the propeller on the hull. This leads to new, corrected parameters of flow on the hull and new velocity field at propeller. This cycle of computation is repeated until the influences of hull on propeller and propeller on the hull are fully converged and the so called self propulsion condition of the ship is reached. Analogical computation of the influence of viscosity on the hydrodynamic pressure field generated by the hull may be conducted without influence of the propeller. Fig. 1 presents results of such computation for the ship M445 in model scale.

Analysis of such computations for different hull geometries leads to the conclusion that the influence of viscosity accounted for by an appropriate hull thickenning has only limited effect on the values and distribution of the hydrodynamic pressure generated by the hull. This effect would have been more pronounced if separation of flow were present in the stern section of the hull. However, such separation is rare in typical naval ships.

Despite this small direct effect of viscosity on the hydrodynamic pressure generated on the hull it is still necessary to determine the boundary layer parameters because it enables calculation of the non-uniform velocity field at propeller. The effect of propeller operation on the hydrodynamic pressure field is usually much more pronounced, especially when cavitation is present on the propeller blades.

THE INFLUENCE OF PROPELLER OPERATION ON THE HYDRODYNAMIC PRESSURE FIELD

The influence of propeller operation on the acoustic pressure field is obvious. However, similar influence on the hydrodynamic pressure field is less studied. Two different types of this influence may be defined, namely direct and indirect influence. The indirect influence demonstrates itself through propeller-induced changes in the hull flow, including the flow inside boundary layer. The direct influence stems from the principle of propeller operation, which results in generation of velocity and pressure fields directly into surrounding volume of fluid. This field demonstrates itself as characteristic discrete lines in the acoustic spectrum, having frequences related to multiples of propeller rotation and number of blades. The measurements of hydrodynamic pressure field in full scale or on self-propelled models include this pressure induced directly by the propellers.

One of the working hypotheses reducing the computational pressure field due to propeller operation to joint hydrodynamic pressure field is based on determination of the effective pressure from the propeller, namely on calculation of the hydrodynamic pressure directly induced by the propeller according to the formula:

$$p_{\max} = \sqrt{\sum p_{inz}^2}$$

where: p_{inz} - amplitudes of respective harmonics of the propeller-induced pressure

Pressure calculated in such a way is added in corresponding points to the hydrodynamic pressure generated by the hull, which already contains the effect of indirect propeller influence.

In the computer program CISAKU the pressure field directly generated by the propeller is calculated by means of the thoroughly experimentally verified computational model based on the unsteady deformable lifting surface theory, particularly suitable for detection of cavitation on propeller blades and for determination of cavitation-induced pressure field [4].

Fig. 2 shows the results of calculation of the hydrodynamic pressure generated by the ship model M445. There are three curves in the diagram: first without propeller influence, second with indirect propeller influence and third with both direct and indirect propeller influence. Two last lines practically coincide, which means that the direct propeller influence on the hydrodynamic pressure field is negligible. It should be kept in mind that no cavitation was present on propeller blades in this case. As it is widely known, in full scale ships significant direct propeller influence is frequently detected. Usually it is attributed to cavitation.

Fig. 3 presents the results of calculations for the ship M445 in full scale. Propeller rate of rotation has been adjusted to produce different forms of cavitation, which are detected by the computer program. At 3.0 revolutions per second vortex cavitation appears, at 3.25 revolutions per second sheet cavitation starts and at 3.5 revolutions per second cavitation is already fully developed. This form of cavitation influences very markedly both the values and distribution of the hydrodynamic pressure field. These results confirm the decisive effect of cavitation on the level of hydrodynamic pressure generated by ships.

CONCLUSIONS

The computer program CISAKU enables effective analysis of the influence of several factors affecting the level of ship-generated hydrodynamic pressure. The analysis presented in this paper has shown that in many cases simple computational models, which do not account for the effect of viscosity or propeller operation, may produce realistic calculations of the ship-generated hydrodynamic pressure field. However, in full scale cases with cavitating propellers more sophisticated methods, such as the program CISAKU should be used.

The above mentioned computer program may be used for evaluation of the ship hull and propeller geometry from the point of view of generated acoustic pressure field at an early design stage. Consequently, it may become an useful design tool for optimisation of naval and special ships.

REFERENCES

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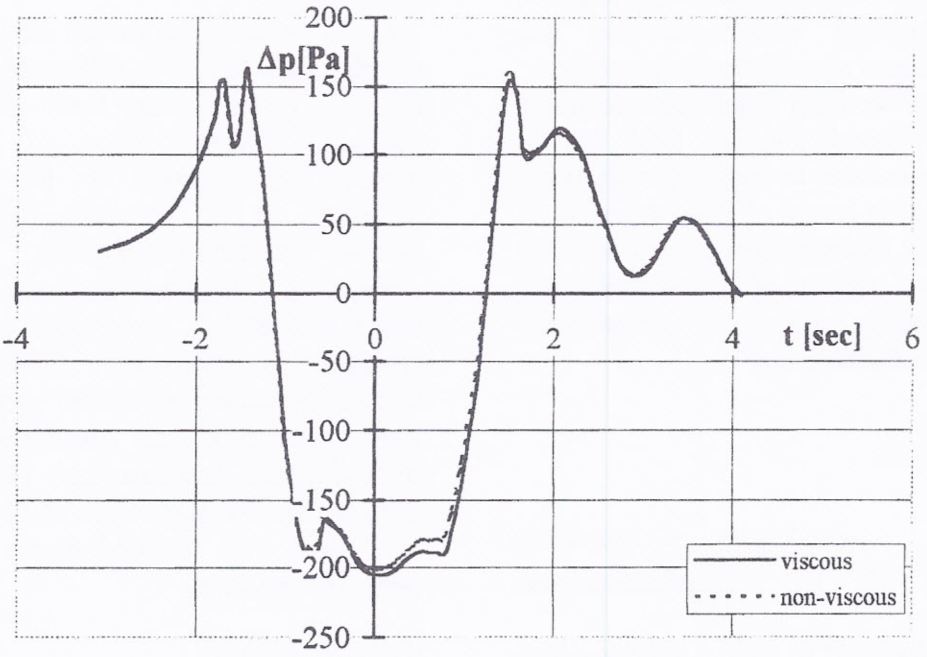

Fig.1 Comparison of the influence of viscosity on the pressure distribution Δp for the model M445 including the wave system. Calculation point is located in the hull plane of symmetry at depth $z_0/T=2.0$. Sea bottom is located at $h/T=4.0$. Bottom reflection coefficient $\alpha_{od}=1.0$. Froude number $Fr=0.258$.

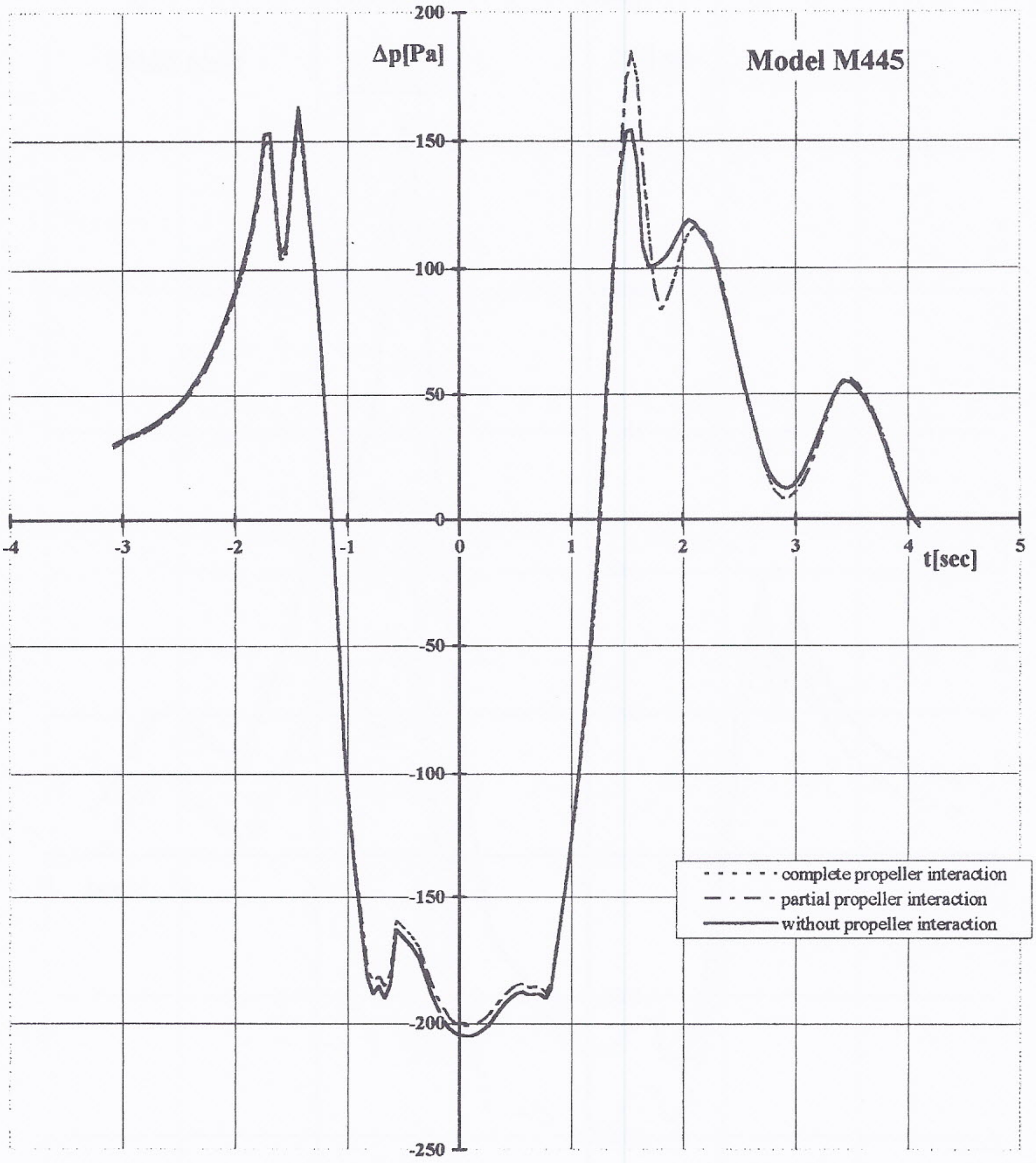

Fig.2 Model M445. Influence of propeller operation on the pressure below moving model at depth *Z*=0.80m (total pressure and pressure with indirect propeller effect coincide)

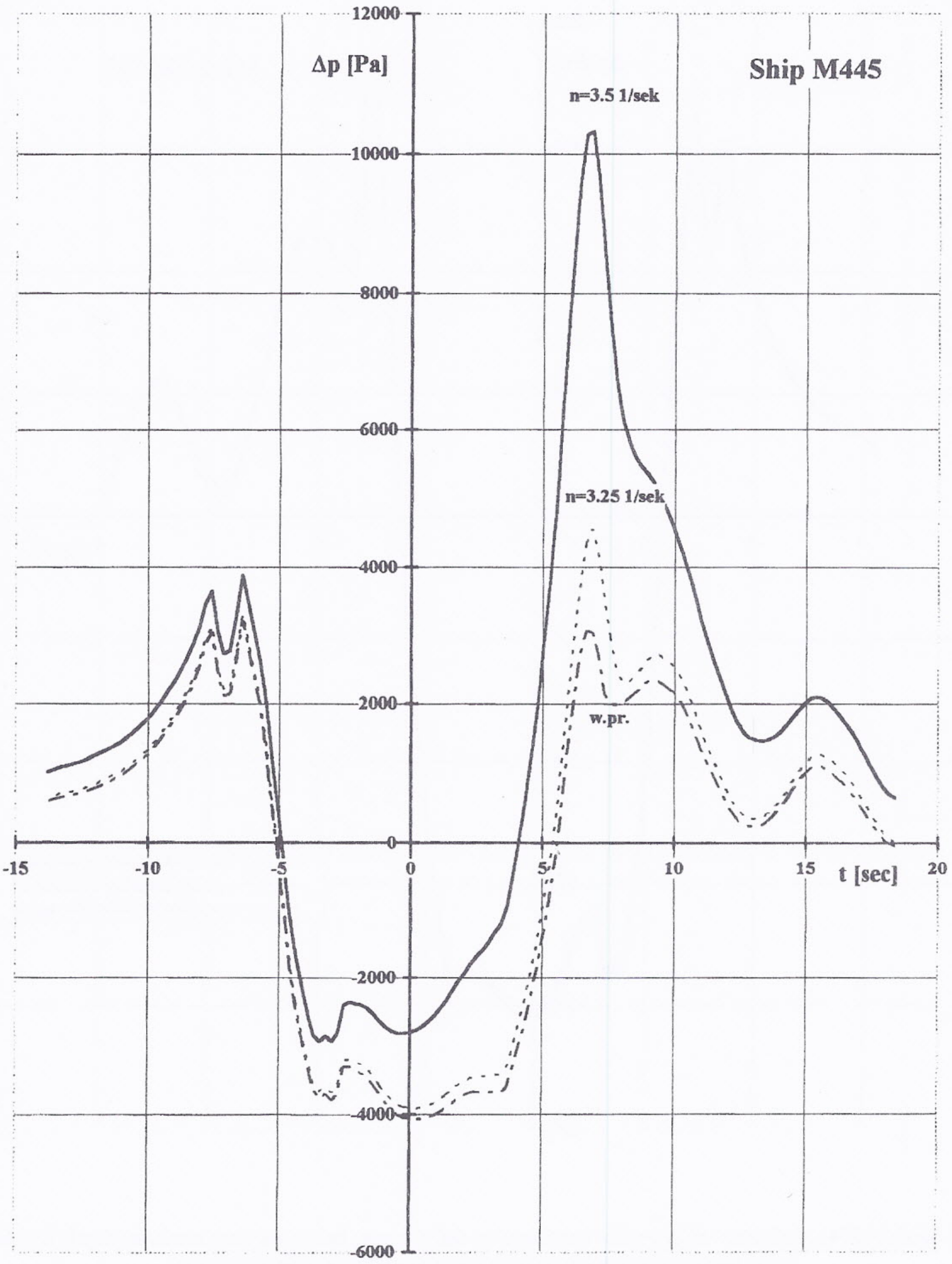

Fig.3 Ship M445 in full scale. Influence of propeller rate of rotation (cavitation) on the pressure below moving ship at depth Z=16.0m.