PROPELLER-HULL INTERACTION RESEARCH AT IOWA INSTITUTE OF HYDRAULIC RESEARCH

1985-1989

by

F. Stern and V.C. Patel

Sponsored by

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Accelerated Research Initiative Program in
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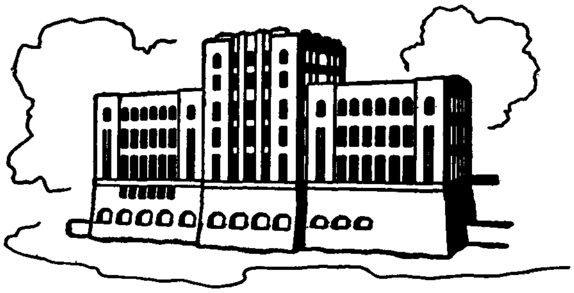

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Iowa Institute of Hydraulic Research
The University of Iowa
Iowa City, Iowa 52242-1585

August 1989

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ABSTRACT

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TABLE OF CONTENTS

I. INTRODUCTION

The purpose of the research on propeller-hull interaction conducted at the Iowa Institute of Hydraulic Research (IIHR) was to develop computational methods to determine the interactive and combined flow field over the stern and in the wake of a propeller-body configurations and to acquire experimental data for three-dimensional and axisymmetric bodies to explicate the physics and validate computational methods. In addition, the initial development was done of a method for calculating viscous flow around rotating propeller blades to simulate the complex blade-to-blade flow.

The experiments for the three-dimensional body were performed in cooperation with I. Tanaka and Y. Toda, Osaka University, Japan. Both F. Stern [1] and V.C. Patel visited Osaka University to help plan and coordinate the experiments. Y. Toda visited IIHR from April 1988 through March 1990 to work on this and another ONR research project.

In the following, an overview of the research is presented. A list of publications which describe the detailed results is also provided.

II. RESEARCH PERFORMED

A. Experimental Studies

1. Iowa Axisymmetric Body

The Iowa axisymmetric-body experiments were performed in IIHR's 1.07 m, octagonal, open-throat test section, closed circuit wind tunnel. The body length and diameter were 151.6 cm and 13.91 cm, respectively. The propeller was designed and constructed by Hydrodynamics Research Associates according to standard Navy practice for wake-adapted propellers. The propeller diameter $D_p = 13.91$ cm was chosen so that it is fully immersed in the thick boundary layer on the stern of the body. The following measurements were made for the bare-body, spinning-hub, and with-propeller conditions: surface-pressure distribution; steady mean-velocity and pressure with a five-hole pitot probe; and steady and unsteady mean-velocity and turbulent stresses with a triple-sensor hot-wire probe. Ref. [2] provides an overview of the experimental arrangement, measurement system, and results, with special emphasis on the use of a triple-sensor hot-wire probe in a flow involving periodicity, large flow angles, and high turbulence levels. A more detailed description of the experiments and the complete set of data may be found in the forthcoming Ph.D. thesis of Hyun [3].

2. Series 60 $C_B = .6$ Ship Model

The Series 60 $C_B = .6$ ship model experiments were performed in the Osaka University, Department of Naval Architecture, towing tank. The towing tank is 100 m long, 7.8 m wide, and 4.35 m deep. Two 4 m models were constructed for the experiments: a wooden model used for the mean-velocity and pressure field measurements with two five-hole pitot probes; and a fiber-reinforced plexiglass model with pressure taps used for the surface-pressure measurements. A 145.64 mm diameter, 5 bladed propeller with MAU sections was used. Measurements were performed for both the with- and without-propeller conditions at numerous stations both upstream of the propeller and in the near-wake region. Also, wave profiles were measured for both conditions, and resistance and self-propulsion tests were conducted. The experiments were performed at low Froude number, $Fr = .16$, to minimize free-surface effects. The with-propeller measurements were performed for the model self-propulsion condition. Refs. [4,5,6] provide descriptions of the experimental equipment and procedures, and the results are discussed to point out the essential differences between the flows with and without propeller. The results are analyzed to assess the nature of the interaction between the propeller and the hull boundary layer and wake. To this end, use is made of a propeller-performance program with both nominal and effective inflows. It is shown that most features of the interaction can be explained as a direct consequence of the propeller loading resulting from its operation in a three-dimensional nonuniform inflow.

B. Computational Studies

1. Interactive Approach

A comprehensive viscous-flow approach to propeller-hull interaction has been developed in which the IIHR viscous-flow method for calculating ship-stern flow is coupled with a propeller-performance program in an interactive and iterative manner to predict the combined flow field; hereafter referred to as the interactive approach [7,8,9,10,11,12,13]. A body-force distribution is used to represent the propeller in the viscous-flow method. Calculations have been performed for propeller-shaft configurations [8,9,11], axisymmetric bodies [7,9,12], a simple three-dimensional body (DTRC 3:1 elliptical body) [8,10], and a realistic ship model (Series 60 $C_B = .6$) [13]. In most cases, the calculations have been verified through comparisons with experimental data. In general, the steady-flow results show good agreement with the experimental data and indicate that such an approach can accurately simulate the steady part of the combined propeller-hull flow field. However, consistent with bare-body calculations, the most detailed comparisons [12,13] indicate the need for improved turbulence models. Although the unsteady-flow results generally follow the trends of available data, these indicate the limitations of this approach for simulating the complex blade-to-blade flow.

2. Complete Viscous-Solution Method

Initial development was done of a method for calculating viscous flow around rotating propeller blades to simulate the complex blade-to-blade flow; hereafter referred to as the complete viscous-solution method. This work was motivated by the limitations of the interactive approach, as described above. Refs. [14,15,16] provide descriptions of the computational method, and present and discuss results with regard to the flow physics for both laminar and turbulent flow, for the idealized geometry of a propeller-shaft configuration with infinite-pitch rectangular blades. It is shown that the flow exhibits many of the distinctive features of interest, including the development and evolution of the shaft and blade boundary layers and wakes, and tip, passage, and hub vortices. Also considered are the influences of a thick-inlet boundary layer, the propeller angular velocity, and the blade number. Comparisons are made with some relevant experimental and computational studies, including results from a lifting-surface propeller-performance program, to aid in evaluating the present method. Close similarity and consistency are demonstrated. The latter case shows that the present method accurately predicts the blade loading, including viscous effects, and clearly displays the ability to resolve the viscous regions in distinction from the inviscid-flow approach.

III. PUBLICATIONS

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[13] Toda, Y., Stern, F., and Kim, H.T., "Computation of Viscous Flow Around Propeller-Body Configurations - Part 2: Series 60 $C_B = .6$ Ship Model," in preparation for submittal to the Journal of Ship Research.

[14] Kim, H.T., "Computation of Viscous Flow Around a Propeller-Shaft Configuration With Infinite-Pitch Rectangular Blades," Ph.D. Thesis, Department of Mechanical Engineering, The University of Iowa, May 1989.

[15] Stern, F. and Kim, H.T., "Computation of Viscous Flow Around a Propeller-Shaft Configuration With Infinite-Pitch Rectangular Blades," Proc. 5th Int. Conf. on Numerical Ship Hydro., Hiroshima, Japan, September 1989.

[16] Kim, H.T. and Stern, F., "Computation of Viscous Flow Around a Propeller-Shaft Configuration With Infinite-Pitch Rectangular Blades," submitted to the AIAA Journal of Propulsion, August 1989.

IV. CONCLUDING REMARKS

Significant advances were made both in the development of computational methods and in the acquisition of experimental data for the problem of propeller-hull interaction as a result of IIHR's participation in the Office of Naval Research, Accelerated Research Initiative Program in Propulsor-Body Hydrodynamic Interactions. The accomplishments and high level of activity, as summarized above, have had and are expected to continue to have a large impact on the academic and research programs at The University of Iowa.

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