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IRROTATIONAL FLOW WITHIN THE BOUNDARY LAYER AND WAKE

THE FOURTH GEORG WEINBLUM MEMORIAL LECTURE

by

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PREFACE

To be invited to present the Weinblum Memorial Lecture is one of the highest honors that can be bestowed in the field of ship hydrodynamics, and I would like to thank the binational Memorial Committee for selecting me to follow such eminent predecessors as John Wehausen, Otto Grim and Takao Inui. A common feature, of the first four lecturers is that we had been associated with Georg Weinblum, as friends and colleagues, for many years, Wehausen and I since he came to the David Taylor Model Basin in 1948, Grim since he returned to Germany as the first Director of the Institut für Schiffbau in 1952, and Inui since a visit to the Institut in 1960. This will not always be the case, so that it is important that those of us who enjoyed his warmth and inspiration should reminisce about the man and his accomplishments.

When he arrived at the David Taylor Model Basin in 1948 at the age of 51, he was already well known for his many publications on ship hydrodynamics. Soon he had many personal friends. John Wehausen, Phil Eisenberg and I would regularly stop at his office to take him to lunch. We invited him frequently to our homes in the evenings. When he decided he needed to walk several miles along the highway from the laboratory after work, he had to decline many offers of rides from passing employees. He was very popular.

Georg arrived at the David Taylor Model Basin at an opportune time when a relatively young group, with little previous experience in ship theory, had been assigned to study and perform research on almost all aspects of ship hydrodynamics. His influence was immeasurable. In a warm and persuasive manner, with humor, insight and reason, he communicated easily with all, from the Directors of the laboratory to the lowliest assistants. With his sound grasp of the fundamentals and his vast knowledge of the literature, he served as a catalyst for the research productivity of his colleagues.

His promotional activities assumed several forms. Most evident today are the TMB Reports that he wrote in which he indicated the state of the art and what he considered to be the problems requiring investigation. Another of his techniques was to invite the staff to his lecture on a topic on which he felt we should be more knowledgeable. I vividly recall two...
such lectures, one on hydrodynamic mass, the other on the Lagally theorem. Curiously, although, in the first lecture, he waved aside as impossibly large an inertia coefficient I had measured for an accelerating ship model, and, in the second lecture, I was skeptical about the validity of the Lagally theorem, the seed he planted took root and I have written many papers on these two subjects in the succeeding thirty years.

On the subject of ship wavemaking, for which he was renowned, he influenced many of the staff, not only by his published papers and his TMB Reports, but also by his personal inspiration. Then Hartley Pond wrote an important paper on the pitching moment on a submarine near a free surface, and William Cummins, in a milestone paper, generalized the Lagally theorem to unsteady flows and applied it to study the force and moment acting on a body of revolution moving under a train of surface waves. His greatest success, in my opinion, was in interesting John Wehausen in ship wavemaking, a field to which Wehausen and his students at Berkeley have been making major contributions for over twenty years.

These were also productive research years for Georg Weinblum. One work, in particular, with J. Kendrick and M.A. Todd, DTMB Report 840, November 1952, entitled "Investigation of Wave Effects Produced by a Thin Body - TMB Model 4215," is closely related to the theme of the present lecture. The aforementioned model was essentially a plank, thickened for structural reasons to a length-to-thickness ratio of 40. It was designed and tested in order to determine the effect of paint roughness on frictional resistance. Weinblum observed, however, that the measured resistance showed indications of wave resistance, and that the thinness of the form offered an unusual opportunity to test the Michell thin-ship theory. Hence, with his assistants, he undertook to calculate the wave resistance of the model from the Michell integral, a major task in pre-computer days. Although they obtained satisfactory agreement with the residyuary resistance, perhaps of even greater significance is that their work has served as the basis for testing refinements of ship wave theory in a 1975 paper by K.W.H. Eggers and H.S. Choi at the First International Conference on Numerical Ship Hydrodynamics, and the basis for trying a procedure for including viscous effects in wave-resistance calculations in a 1980 Ph.D. thesis by S.-Y. Kang at The University of Iowa.
An area that he had promoted strongly was that of the behavior of a ship at sea. After convincing the Director of the importance of this field, he was dismayed to discover that it had been decided to invest millions of dollars in the design and construction of a huge seaworthiness facility. Although he was a firm believer in the need for experimental data to confirm theoretical results, or to guide the development of a mathematical model, his opinion was that a team of analysts could produce more useful results at a fraction of the cost. He emphasized this by presenting a paper, with Manley St. Denis, on the motions of a ship at sea, at the 1950 meeting of the Society of Naval Architects and Marine Engineers. St. Denis continued in this field, pioneering with W.J. Pierson in developing a theory for predicting ship motions in random seas. He also succeeded in interesting Victor Szebehely in the phenomenon of ship slamming, on which Szebehely continued to contribute for many years. These are two more examples of the far-reaching consequences of Georg's inspiration.

I know of only one case where Georg's persuasive power failed. St. Denis was studying for the Ph.D. degree at The Catholic University of America. His adviser, Max M. Munk, was developing a "lump" theory of turbulence at the time and wanted St. Denis to work in that field with him. St. Denis, however, was not interested in turbulence, preferred to select a problem on seaworthiness, and asked Weinblum to intercede for him. Georg, of course, knew about Max Munk, the famous aerodynamicist, but feared that the converse might not be true. Against his better judgment, he agreed, but as he told me later, the meeting was a disaster. Munk showed no respect for the stature and opinion of his eminent former countryman, and St. Denis had no choice but to write a thesis on the lump theory of turbulence.

Many of the staff at the David Taylor Model Basin who came into contact with Georg Weinblum during those years eventually departed to become Directors of laboratories, (John Breslin of the Davidson Laboratory, and Phil Eisenberg and Marshall Tulin of Hydronautics), or professors at universities, where research in ship hydrodynamics is vigorously pursued. In retrospect, it seems to me that the flowering of research and progress in this field in the United States in the last few decades is, in a good measure, attributable to his influence. The following quotation from a paper on both added masses and the Lagally theorem, published in 1956 in the
Journal of Fluid Mechanics, expresses my sentiments:

"We are also pleased, here, to mention Georg Weinblum of the University of Hamburg, that most inspiring teacher, who pointed out the power of the Lagally theorem and new fields of research for many of us."
INTRODUCTION

In a previous work [1], relationships between the flow exterior to a boundary layer and wake, and the concept of displacement thickness and source distributions which generate the outer irrotational flow were examined. Refinements of the source-distribution formulae of Preston [2] and Lighthill [3] were presented for two-dimensional and axisymmetric bodies in a uniform stream. An experimental result given by T.T. Huang et al [4], that the pressure distribution of the irrotational flow continued into the region of the boundary layer and wake is in good agreement with the measured pressures in that region, suggested that this equivalent irrotational flow might be useful in several current problems of ship hydrodynamics.

Many investigators have attempted to take the presence of the boundary layer and wake into account, in calculating the wavemaking resistance of a ship form, by thickening the body by its displacement thickness. In the present approach, one seeks a source distribution which generates the irrotational flow exterior to the boundary layer and wake, and then determines the wave resistance associated with this source distribution. Application to the Weinblum-Kendrick-Todd form [5], which is essentially a thin plank of 40 to 1 length-to-thickness ratio, reported in the Ph.D. thesis of S.-Y. Kang [6], showed that agreement with the measured residuary was considerably improved by modifying the source strengths for the effects of viscosity.

Similar procedures are currently being applied to the Wigley parabolic ship form. For this application, an extension of the analysis in [1] to the case of a ship form is required. Although, in general, it will probably be necessary to use integral-equation methods to determine the equivalent irrotational flow, the special geometry of the Wigley form,