MUSINGS ON SHIP WAVES: 1950-2000
FRIENDSHIPS, LUCK, AND CURIOSITY

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FORWARD

A life in Research can yield rich and productive personal relationships, sometimes weblike, of random, unplanned character. Our Curiosity about, and Investigations of a given subject may be bound up in these webs too. This is seldom described or evoked in Literature, where we are satisfied with an austere, impersonal, presumably rational style.

After several false starts I have settled here, to tell on this Occasion my own story about Ship Waves, with many technical details which I hope will interest the younger audience, but interwoven with Musings of a personal nature, so that finally the Connections and Webs which form both the personal, professional, and scientific sides of our lives can be seen in their waxing and waning.

So Georg Weinblum and Lou Landweber appear at the very beginning of this story, and later, many, many others, and no one as true a friend or as talented or congenial a Collaborater as Touvia Miloh, whom we are celebrating here now.

And at the End, Maurizio Landrini blazes fiercely across our sky, and we both celebrate and mourn his Passage.

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The complete paper, which will appear later in the JSR is organized in five Chapters, one for each Decade. There is space here to present only a selected Listing of the contents, plus some Technical Questions from the complete paper, plus a full sample chapter, the 1980s. I have chosen this decade mainly because Touvia appears first there.

There appear below as in the full paper, between asterisks (***), Technical Questions and/ or Commentary, usually of a basic nature, which are addressed especially to the Curiosity of the Younger Scientists amongst you.

The 1950s

Arriving at DTMB from Langley. Complete ignorance of Ships, Ship Waves, or Cavitation. Georg Weinblum's thin plate experiment and validation of Michell's Theory. Suggesting the Wake Momentum Survey for Ships. Lou Landweber's important role: "So without Lou I would certainly not be here today, and neither, I suspect would Touvia". Doing a ship resistance experiment with Ralph Cooper in the $140'$ basin with a falling weight dynamometer and discovering a residuary resistance curve with a loop in it (non-uniqueness). Philip Eisenberg and the unique East End Fluids Laboratory at DTMB.

Moving to ONR and our support of Naval Hydrodynamics. Becoming aware of Ship Internal Waves. Planning the First ONR Symposium on Naval Hydrodynamics. Weinblum and Freeboard. Initiating the Berkely Program. John Wehausen and his influence. Hunter Rouse and the Iowa Program. ONR London and meeting James Lighthill, George Batchelor, and Fritz Ursell.

****Is it possible that in consideration of wave non-linearities and wave breaking, that the wave pattern and the wave resistance of a ship are under certain circumstances not unique?****

The 1960s

Founding Hydronautics with Phil. Bulb research (T.Inui) and Boyun Yim. Wave Free Singularities. Wave Free Cavities and Small-Wave Bodies. Blunt Bows and collaboration with Gideon Dagan. The naive Froude number expansion (Francis Ogilvie). The existence of flows before blunt bows and Ernie Tuck.

****The fundamental question whether rising, potential free surface flows before bluff bodies exist at all, or under what circumstances, still remains* *open, as are questions related to the stability of such flows and the nature of the disruptions which are observed****

The 1970s

Weak Nonlinearities–Breaking away from Michell. Dagan, 1972, extends his ship wave analyses beyond the bow problem. The rise of 'slow ship' theory: Dagan, Baba, Newman, Maruo, Dawson. The great hope for a practical computational prediction method. Straining Theory. Japanese activity: Inui-Kajitani, Maruo, Baba. Inui's Seminar on Ship Wave Theory,1976. "Ship Wave-Resistance-A Survey", National Mechanics Congress, 1978. Ray Theory. The computational era looms.

The 1980s

Exact Theory. Strong Nonlinearities. UCSB. Dead Water.

But what were the relations and connections between these various approximations: ray, "slow ship", second order, formal straining, and Guilloton? It occurred to me that it would be instructive and useful to answer these rather deep questions in the 2d case, which might even be within my personal ability. I had earlier in the 70s become intrigued by the Davies transformation of the non-linear free surface problem, which was revealed in Milne-Thompson's legendary Banquet speech at the First (1956) Symposium on Naval Hydrodynamics, and had done a little work on it. It involved complex analysis and I felt at home. So I set out to extend it from its original application for progressive waves, to include the presence of a submerged wave making body. My hope was that extension of the Davies theory would provide an exact result in analytical form, which even in its complexity could then be subject to various approximations, whose connections could thereby be discerned. And so it turned out.

The attempt resulted in "An Exact Theory of Gravity Wave Generation by Moving Bodies, Its Approximation, and Its Implications" presented at the ONR-SNH, 1982, Ann Arbor. The only follow-up to this paper has been made by Touvia and VandenBroek, who pursued the method to obtain an iterated solution of the classical Stokes wave problem. It was a very good and welcome application of the Davies approximation, extended.

I had succeeded to answer most of the questions which I had asked myself, and, in addition I learned some new and startling things about the nature and mechanics of wave making by a submerged body in 2d. I think these fundamental and new analytical results about wave making remain little known but worthwhile, so I will review them here:

1. The Mechanism of Wave Generation. In the case of waves made by a submerged body or by a pressure distribution acting on the free surface, the exact solution has the form of superimposed waves of continuously changing effective wave number, explicitly related to a precisely defined "non-wave" disturbance, caused by the motion of the moving body or pressure distribution. In the former case the primary wave generation and the modulation of wave length are caused by the local normal pressure gradient which would exist in a free wave given the velocity there.

2. Two Regimes of Wavemaking Exist, 'Weak' and 'Strong'. In the latter case, which occurs when the "non-wave" disturbance is sufficiently large, discrete waves arise at critical points on the surface, whose slope is proportional to $\sqrt{\kappa}$ where κ is the wave number. Therefore the existence of solutions in the strong regime for sufficiently small Froude numbers is brought into question. In the weakly nonlinear regime, where the "non-wave" disturbance is of $0(\epsilon)$, waves originate everywhere and become exponentially small as κ increases.

3. The 'Moderate Speed' Approximation in the Weak Disturbance Case. For the asymptotic case $\kappa\epsilon^2 << 1$ and $\kappa >> 1$ the exact theory reduces to an approximation which was shown to be the same as the following when the 2d case is taken: the second order ship theory theory of Inui-Kajitani, 1977; the 'slow ship' theory of Dawson, 1977; straining theory. The results also show, as had already been deduced by Doctors and Dagan, that Guilloton underestimated the required straining by a factor of 1/2. Therefore, at least in 2d, second-order, straining, and 'low speed' approximations are equivalent, and all are limited to an asymptotic range defined by $\kappa >> 1$ and $\kappa\epsilon^2 << 1$ The theory is therefore not for a given body shape applicable in the limit of vanishing speed, and is therefore not continuous with ray theory. Therefore the name given to the Dawson and similar theories, Low Speed Theory, is a misnomer! In fact, these various theories are applicable neither in the limit of very low or very high speeds.

4. A "Moderate to High Speed" Approximation in the Weak Disturbance Case. There exists in the weak disturbance case an improvement of the "Moderate Speed" limit which eliminates the high speed limitation. It applies in the asymptotic case: $\kappa\epsilon^2 << 1 << \epsilon^{-2}$. In its application the surrogate body flow, corresponding to Dawson's double model flow, is not the double model, but is the arithmetic mean of the double model plus the "free" model flows.

****Do the two Regimes, Strong and Weak, exist in the case of 3d ship waves and what are the consequences?****

****Is it demonstrable through computation to confirm that in the case of the Strong regime that continuous solutions will not exist in the limit of vanishing speed? Does this have anything to do with the inability of Tuck et al to find a continuous solution in the 2d blunt bow case?****

****Do non-breaking flows exist at all for surface piercing ship forms, of arbitrary form and thickness, at any speed?****

In 1982 I had moved to UCSB and founded the Ocean Engineering Laboratory there. In writing teaching notes on Waves, which incorporated some notes I had prepared in 1974 when I taught a course on Marine Hydrodynamics with Julian Cole at UCLA. I was struck by the ubiquitous appearance of Rays in various wave generation problems, mostly in 2d. This made me very curious about their application to Ship Waves, and when I received word that I had been selected to give the 1984 Weinblum Lecture in Hamburg on the occasion of the 15th ONR/SNH, I decided to work out the asymptotic low speed theory of both thick ships and of 3d surface pressure distributions, including the prediction of the wave amplitudes, which was missing in the earlier theory of J. Keller, 1979.

I learned a lot in that process including the fact that the Kelvin-like patterns seemingly generated at the bow and stern were not identical to the classical Kelvin pattern, but were modified depending on the magnitude of the entrance and exit values at the bow and stern. The theory for the wave amplitude showed that the latter depended on the pressure gradient in the surrogate (double model) flow normal to the hull at the surface. For normal bows and sterns this quantity blew up at these points. Indeed, the entire theory, which required that waves be generated only at singularities on the hull as determined by the double model flow there seemed not useful, and the more so in view of Ogilvies suggestion that the flow closest to the bow was like a high speed flow.

On the other hand, the ray theory for the waves produced by 3d surface pressure distributions seemed both useful and very interesting, since waves could be generated from all points of the boundary. Among other things the theory was able to predict the appearance of caustics in the flow away from the pressure distribution. I was happy with this successful application because of its familial connection with Georg Weinblum's very early work on wave making by 3d pressure distributions, 1930.

****Does an asymptotic low speed theory of thick ships really exist (see previous questions), and if so what is its correct form?****

Touvia visited the OEL at UCSB on sabbatical in the mid-80s and during a walk on the East Beach I said, "We've never done any mathematics together. Why don't we do something now? Why don't we try to understand the old Dead Water observations of Ekman?" So we studied Ekman's 1904 writings and the fascinating observations of mariners which he had collected. Soon Touvia had worked out the asymptotic theory for thick ships in shallow pycnoclines, which reduced to an analogous gas dynamics problem, where the transonic regime corresponded to the Dead Water cases, and is nonlinear. The high speed cases, supersonic, corresponded to modern ships and we could do calculations using characteristic methods. So we wrote and published some papers together, and had gained considerable insight, even given the restrictions of the approximations. We talked a lot and argued some, especially about Touvia's predeliction for non-linear spectral methods, and my more old fashioned inclinations. It was great fun. There was more to come, including a nice and interesting paper by Touvia and Zilman using Singularity Methods to calculate the actual near and far field wave patterns in two layer flows, including the near critical speed case, which received the Best Paper Award at an OMAE Meeting. This was followed by Touvia's work on internal wave Solitons.

****Can actual observations of strong and nonlinear dead-water patterns around ships near the critical speed, as in Ekman, be reproduced in model tests, and can they be predicted by numerical calculation?****

The 1990's

Maruo at UCSB and the problem of water on deck. The development of Computational Nonlinear $2D + t$ by Maruo and applications to ships in waves (Song and Wu). Application to breaking bow waves. Their monochrome nature. Understanding Inui and Miyata's bow "shock waves". The stern 'rooster tail' and the generation of the divergent wave wake. The success of nonlinear $2D + t$ in predicting the entire divergent wave field and comparison with Raven.

Touvia and internal wave Solitons in shallow pycnoclines. OEL systematic model experiments on ship internal waves. OEL predictive nonlinear theory of supercritical ship internal waves in general density distributions (Pei Wang). The discovery and investigation of 'Quasi-Solitons' (YiTaoYao).

Bow Waves and Ship Wakes—Helping Ed Rood at ONR. Particle methods and E. Fontaine. The Smooth Particle Method. Jet Impact.

Maurizio Landrini at the OEL. Developing SPH for free surfaces. Dealing with post breaking-splashing and entrainment, the generation of multiple vortical flows. Simulating the Bore in shallow water—a validation of our technique. Investigating the breaker splash: discovering the ricochet and backward splash and the generation of vortical regions and their interaction. Aeration and the tunnels under broken bow waves. Breaking wave patterns.

Simulating and understanding transom waves with $2D + t$. The cavity. The rooster tail. Breaking stern waves. Ideas about combining $2D + t$, SPH, and weakly non-linear or other field calculations.

In Retrospect

Michell's 1898 Paper was a singular event, which seemed to arise without precedent. In this sense, it can be compared to Stokes 1847 paper on progressive waves. And, afterwards, for more than 50 years, Havelock applied linear theory to various wave-body problems, laboring almost alone.

After and during WWII, Courage arose almost spontaneously to tackle non-linear engineering problems, and particularly in fluid dynamics. Linear approaches were put in their place through formal asymptotic analysis, and new techniques arose like inner and outer expansions and matching, and these proved very useful in fluids, to deal with non-uniform convergence, for example.

Ship Waves happen to be especially complex in their mathematics, and the real difficulties only began to be perceived in the 1960s Decade. Nevertheless, despite all complexity, useful non-linear approximations appeared in the 60s and with the computer led to hope about prediction based on theory—it was a great triumph.

As time passed, computer advances finally allowed the fully non-linear numerical calculation of the flow about the ship.

However, two vital regions of the flow were beyond such fully numerical methods: i. the region of breaking and splashing bow waves; ii. the cavity in the transom and the breaking waves produced there; iii. the rooster tail and the radiated divergent wake.

The development in the 1990s, first of the nonlinear $2D + t$ BEM, and subsequently the development of $2D + t$ particle method calculations for free surface problems, SPH, provided tools for the study of all of those regions i, ii, and iii, listed above and this has to a great extent been done—if not finished or completely published.

Looking Forward

I imagine that 1950-2000 will be viewed as a period when the ship wave theory reached a certain maturity, and the way ahead lay almost entirely in the further utilization of computing power applied to appropriate algorithms. I can imagine the following future:

1. The development of particle methods based on the Euler equations for fully three dimensional unsteady computations of flow past ships utilizing parallel methods and arrays of pc's.

   I believe that this is presently possible, and even economical. Such techniques would have no restrictions on wave breaking or splashing, but would not necessarily include air entrainment and two phase flow effects.

2. Beyond that, viscous stresses, and entrainment and multi-phases will be dealt with in such 3d codes. Keep in mind that particle methods based on the Euler Equations already incorporate Reynold's stresses. These developments will take some time, depending on the financial and people resources devoted to their development.

This means that young scientists interested in ship flows can look forward to having wonderful computing tools available for the scientific study of flow problems, based on Computational Experimentation—where Scientific Curiosity and Computation will meet. Have Fun!

Computational results, as experimental results, do not take the place of the deep understanding of physical processes which we should always place high in our priorities. For this deep understanding, mathematical descriptions and analysis, as well as their prose analogs are and will always remain primary. We have already made progress which outstrips our physical and mathematical understanding. So there remains plenty for Analysis in the future. Not to speak of the very important mathematics which needs to be done in connection with these new computational methods.