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Ernest Oliver Tuck 1939–2009

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Ernie Tuck was one of Australia's most outstanding applied mathematicians, with an international reputation as a leading authority on water waves and ship hydrodynamics. He made seminal and incisive theoretical analyses in many areas, especially on wave resistance of slender ships and wave interaction with obstacles. His work is characterized by his ability to find the essentials of a complex problem, and then to apply apparently simple, but revealing analyses, using a combination of perturbation and asymptotic techniques with numerical calculations. He was an outstanding expositor, supervised twenty-five doctoral students, and will be remembered by his many colleagues as a brilliant scientist and an enthusiastic and caring person.

Ernest Oliver ('Ernie') Tuck was born in Adelaide on 1 June 1939. His father, Frank Ernest Tuck, was a staff sergeant in the Army Engineers, based in Unley, South Australia. After the early death in 1946 of his father in a car accident, Ernie and his younger brother Robert were raised by their mother, Jean Edith Pocock (née Probert) who died in 2006. Ernie received his primary and secondary education at Unley Primary School and Unley High School (1951–5), and then went on to study pure and applied mathematics and physics as an undergraduate at the University of Adelaide, 1956–9. He graduated BSc (Hons) in Mathematics in 1960. It was here that he first met Professor Ren Potts, OA, FAA, whose interests in operations research and statistics provided the topic of Ernie's first research paper (1). It was a connection that would resume when Ernie returned to the University of Adelaide.

Then in August 1960 Ernie, having been awarded a Sir John Gellibrand Scholarship by Legacy Australia, sailed to England and enrolled as a graduate student at Trinity College, University of Cambridge, studying in the Department of Applied Mathematics and Theoretical Physics. Here his supervisor was Professor Fritz Ursell, FRS, and Ernie entered the field of fluid dynamics with a focus on water waves that would remain his life-long major research interest. When Ursell moved to take up the Beyer Chair of Applied Mathematics at the University of Manchester at the end of 1961, it was arranged that Ernie spend his second year at Cambridge and his third year at Manchester. In 1964 Ernie was awarded a PhD for his thesis: 'The steady motion of a slender ship'. Ernie had proposed to Helen Lorna Wood the day before he left for the UK in 1960, and she came to Cambridge the following year. They were married in Trinity College Chapel on 21 October 1961. Helen was the daughter of Thomas George Wood, GM, a Squadron Leader in the Royal Australian Air Force in Albury, New South Wales (deceased in 1954) and Essie Lorna Wood (née Hincks, deceased in 1998). Ernie and Helen had two sons, Warren James Tuck, born in Washington, DC in 1965, and Geoffrey Neil Tuck, born in Adelaide in 1969. Warren graduated in 2008 with a BEng (Computer Systems) from the University of Adelaide and now works for the South Australian police force. Geoffrey graduated in 1994 with a PhD in applied mathematics from the University of Adelaide, and now works as a fisheries scientist with the CSIRO Marine and Atmospheric Research Division in Hobart, Tasmania.

Fritz Ursell was a major figure in UK and international applied mathematics, with a special interest in water waves and ship hydrodynamics. Hence Ernie's PhD topic on the application of slender-body theory to the calculation of wave resistance by a steadily moving ship was a natural choice. But it also reflects Ernie's lifelong interest in applying mathematics to natural phenomena, often arising from his own personal observations. Slender-body theory for ship hydrodynamics was a completely new field and Ernie's approach, based on the method of matched asymptotic expansions, was revolutionary. An indication of the impact of this work is that after his second year at Cambridge, a small meeting, sponsored by the US Navy's Office of Naval Research (ONR), was organized at Wageningen, Netherlands, to discuss his research and the complementary work of Gerrit Vossers on the same topic. That meeting was also attended by the Americans, Nick Newman and Francis Ogilvie, a connection that helped to shape Ernie's career.

At the end of 1963, Ernie took up a position as a Research Mathematician at the David Taylor Model Basin, a research facility of the US Navy located just outside Washington, where he stayed until the end of 1966. Here he linked up again with Nick Newman and Francis Ogilvie. Then in 1967 Ernie took up a position as Senior Research Fellow in Engineering Science at the California Institute of Technology (Caltech) in Pasadena, where he worked with Professor Ted Wu, an inspiring international leader in ship hydrodynamics. In these two periods he worked on a wide variety of research topics in ship hydrodynamics, acoustics, bio-fluid mechanics and numerical analysis. His contributions to these fields were based primarily on analytic methods, but it was during this time that the possibility of numerical simulations using high-speed computers emerged. Ernie was quick to embrace this developing field and combined his theoretical analyses with practical and illustrative results obtained numerically. Two of his most exciting papers at this time were published in the *Journal of Fluid Mechanics* (8, 10). The first reported numerical simulations of nonlinear waves generated by a submerged two-dimensional dipole in steady motion, where the finding that the streamlines included jets emerging from the free surface created great interest. In the second paper Ernie addressed the squat problem where ships at high speeds in shallow water can sink vertically. Using his slender-body theory in the nonlinear shallow water equations, Ernie obtained an elegant and simple theory of great value to ship operators.

In 1968 Ernie returned to the University of Adelaide, initially as Reader in Applied Mathematics. In 1974 he was promoted to a Personal Chair and in 1990, after the retirement of Professor Ren Potts, he became the Elder Professor of Applied Mathematics, named after Sir Thomas Elder, a renowned Australian pastoralist, businessman and benefactor of the University. He remained at the University of Adelaide until his retirement in June 2002, when he became an Emeritus Professor. During his time at Adelaide he served as Head of Department (1974–5, 1980–1, 1983) and then as Dean of the Faculty of Mathematics and Computer Science (1986, 1993–6). He received many honours including election as a Fellow of the Australian Academy of Science (1988), selection as the 1990–1 Georg Weinblum Lecturer (awarded annually by a German-USA committee to honour the distinguished German naval architect), election as a Fellow of the Australian Academy of Technological Sciences and Engineering (1995), and the award of the Thomas Ranken Lyle Medal by the Australian Academy of Science (1999) and the ANZIAM Medal by the Australian and New Zealand Industrial and Applied Mathematics division of the Australian Mathematical Society (1999). From 1984 to 1992 he was Editor of Series B (Applied Mathematics) of the *Journal of the Australian Mathematical Society* and was instrumental in establishing this journal as the leading outlet for Australian applied mathematics. In 2008 Ernie served as President of the International Congress of Theoretical and Applied Mechanics (ICTAM), which took place in Adelaide; this was a prestigious responsibility which he fulfilled with his usual skill and enthusiasm. He spent sabbaticals and made short research visits to many places, including Caltech, Stanford University, the University of Michigan, the University of Delaware, the University of California (Santa Barbara) and the Massachusetts Institute of Technology (MIT), reflecting his standing as an influential and leading figure in the international ship hydrodynamics community. At the same time, he attracted many research visitors to the University of Adelaide. In addition to his frequent participation in the annual ANZIAM conferences, the showcase for applied mathematics in Australia, he was a regular participant in the ONR's Symposia on Naval Hydrodynamics and in the International Workshops on Water Waves and Floating Bodies (IWWWFB). Adding to Ernie's long list of honours, the IWWWFB and the University of Adelaide have established the Tuck Fellowship Fund, endowed by contributions from a large number of individuals from many countries, in order to support participation in these workshops by students and young researchers.

Ernie's published over 180 research articles, characterized by their clarity and conciseness. His research is distinguished by the seeking of new or unsolved problems—often motivated by curious and puzzling natural phenomena—the application of novel mathematical methods, and very careful numerical calculations. He was particularly adept at solving complex problems with simple methods, for instance by his application of the method of matched asymptotic expansions. Notable here are his early work on the wave resistance of slender ships, and the squat problem mentioned above. Later he addressed many other significant problems involving water waves, including wave transmission through small gaps, end effects on blunt slender bodies, and bodies moving near a plane wall or in close proximity to other bodies. Other topics that recur as themes in his publications include the theory of ship motions, Michell's thin-ship theory of wave resistance, planing, bodies with zero wave resistance, nonlinear free-boundary problems, numerical solution of integral equations, low-Reynolds-number flows, wave resistance of multihull vessels, and lifting-surface theory. After his retirement he took up the famous and still unsolved problem of Riemann's hypothesis and was able to make a significant new contribution to the properties of the Riemann-zeta function. Ernie and Helen shared a strong interest in games of chance, especially backgammon and blackjack, and he applied his mathematical expertise here as well. Ernie will be remembered as a brilliant and outstanding Australian applied mathematician, who throughout his long career was a leading international figure in ship hydrodynamics. He was a caring and fun-loving person. The obituaries (B, C, D) and the memorial issue (E) of the *Journal of Engineering Mathematics* give ample evidence of the respect and affection he earned from his colleagues and the international community. He died on 11 March 2009.

Scientific Accomplishments

After his arrival in Cambridge in 1960, Ernie embarked on a theoretical study of the motion of slender ships, producing his PhD thesis (2) in 1964. This was a topic to which he returned often throughout his career, and which forms a major part of his scientific output. Ship hydrodynamics is a classical field that has attracted the interest of scientists and engineers for well over two hundred years, with significant early contributions from Isaac Newton, John Scott Russell, George Gabriel Stokes, William Froude and Lord Kelvin to name only a few. It is a challenging subject, which in essence deals with the interaction of water waves with a floating and moving body. The theoretical formulation, even for an inviscid, incompressible fluid, leads to a nonlinear free boundary value problem. In the absence of a ship, the water-wave problem by itself has been found full of challenges and surprises and remains a very active research field. Ships can both generate waves and be subject to the forces imposed by an extant, usually wind-generated, wave field. The class of problems so generated is large and diverse, and although today high-speed computing power is available, ship hydrodynamics is an active and vibrant research field with theory, numerical simulations and laboratory experiments combining effectively. Ernie entered this field in the 1960s and his work made a huge and immediate impact. Initially he examined the steady motion of slender ships in shallow water. At that time, there was no satisfactory theory for ship motion in shallow water where, in particular, existing theories failed to account for 'squat'. This is a phenomenon in which a ship moving in shallow water experience a downward force. The simple explanation is that the speeding up of the fluid flow beneath the moving ship leads to a vertical pressure gradient through the Bernoulli relation. However, translating this notion into practical and useful formulas for the prediction for squat had proved elusive until Ernie's landmark and highly influential article (10).

There is a close analogy between gas dynamics and shallow water waves, and to some extent this extends to aerodynamics and ship hydrodynamics. When Ernie arrived in Cambridge in 1960, slender-body aerodynamics had already been extensively and successfully developed using the new technique of matched asymptotic expansions. In Ernie's words, the technique was by then 'firmly established as a basic working tool of applied mathematics' (10). His seminal work was first published (5) in 1964 for a slender body in deep water, see also (7) which marks the beginning of his long association with Nick Newman. (In (179) Ernie wrote a biography of Newman, who had a long academic career at MIT.) In (10) Ernie used matched asymptotic expansions to construct explicit formulas for the wave resistance and the forces exerted for a partially immersed slender body in steady motion. The key assumptions were that the body had small beam and draft compared to its length, and that the fluid depth was also small relative to the body's streamwise length. He derived formulas for wave resistance, vertical forces and the pitching moments for both subcritical (that is, a depth Froude number less than unity) and supercritical (that is, a depth Froude number greater than unity) ship speeds. In particular he derived non-dimensional coefficients for sinkage and trim, and found that sinkage is dominant for subcritical and trim for supercritical ship speeds. A singularity when the Froude number approaches unity was later removed by allowing for wave dispersion, which requires that the finite water depth be accounted for (22). The results were compared favourably with available experimental data. But more important than this agreement was the demonstration, apparently for the first time, that applied mathematics could produce useful and significant results in what had seemed to be an intractable problem. This paper, amongst his most heavily cited, was followed by many others on a similar theme. The effect of side walls was incorporated in (13), the effect of a non-uniform depth or channel width in (43, 58), while in (25) the theory was put into an empirical framework to make it more accessible to navigators. In (37) Ernie took up the practical side of 'squat', namely, when a ship moving too fast may hit the bottom. These early papers are remarkable for their maturity and confidence and for the clarity of the exposition. Much later, in (159), Ernie returned to the issue of squat for ships close to the critical speed when the ship's speed coincides with that for long waves, a situation that leads to an enhanced ship-flow interaction. An important feature of Ernie's research was his ability to communicate his research results to the ship engineering community, which he achieved *inter alia* by deliberately publishing in their journals and participating in their meetings. This seminal sequence of papers culminated in his 1978 review article (52) published in the influential *Annual Reviews of Fluid Mechanics*. Although Ernie was by then working in other areas of fluid mechanics as well, he retained a keen interest in slender-body theory applied to ships in particular; see his conference review presentations (102, 130) as well as the articles cited below.

Throughout his scientific career, Ernie developed and applied the basic concepts of slender-body theory in a variety of contexts. Thus as early as 1964, he published in the highly-cited article (4), a method for overcoming one of the principal difficulties with slender-body theory, namely that it may fail at the blunt ends, where there is sharp curvature. In (28) Ernie used the method of matched asymptotic expansions to analyse the inviscid flow of an incompressible fluid (that is, potential flow) under a vehicle moving at a steady speed close to the ground, that is a squat problem for vehicles. This paper also marks the beginning of Ernie's use of numerical methods for solving potential flow problems when the governing equation is Laplace's equation. In this case, the problem has fixed boundaries, but soon Ernie would develop techniques for the numerical solution of potential flow problems with free boundaries. Using an earlier result in (17), Ernie examined in (42) the special case of a ship with zero draft, or 'planing surface', a surf board for instance. As a keen surfer, Ernie returned to this topic several times, in (69, 70, 101, 104, 123, 167, 180). Articles (62, 68, 72, 81, 82) return to the theme of squat, on this occasion for an aerofoil close to the ground in possibly unsteady motion. Articles (75, 76) consider aerofoils with leaflet valves, (96) considers an aerofoil with a trailing-edge flap, (98) considers aerofoils with incident flaps or blunt trailing edges, (117, 137) evaluate an expression for lift on an aerofoil, and (105, 155) examine how the shape of the upstream edge of an airfoil affects how the laminar boundary layer separates. In these papers, as in all his work, Ernie was quick to point out the various physical contexts where his work might be useful, and indeed some papers, (75, 76) for instance, were motivated in part by physiological applications. Article (78) is an application of slender-body theory in an elasticity context. In (88) Ernie presented a theory for flow around an aerofoil close to the sea surface, motivated here by the forward motion of a hovercraft, for instance. In all these works Ernie's deep understanding of the philosophy and use of matched asymptotic expansions is implicitly or explicitly in evidence.

When a ship interacts with a wave field, the flow is intrinsically unsteady and analytical progress more demanding. Historically, most attention was focused on deep-water waves and the ship response to storm-generated waves characterized by relatively short periods and wavelengths. Such waves can, especially when the ship faces into the waves, resonate with the ship's natural heave and pitch frequencies, and the main concern is then with this resonance phenomenon. The most commonly used approach is the so-called 'strip theory'. As Ernie points out in (52, 97), this is essentially a slender-body theory, in which the waves are determined section by section and along-ship interference effects are neglected. It is clear that such a theory is necessarily also a short-wave theory, in which the wavelength is required to be small compared to the ship length. Although strip theory is limited to linear wave theory and there are difficulties with its formal derivation, it has remained popular with ship operators as it is relatively easy to use. In (19, 23, 24) Ernie addressed some of these issues; publication (24) produced the famous Salvesen-Tuck-Faltinsen formula which is still in practical use today, while the results from (19) are often cited as the Ogilvie-Tuck formulas. Ernie had a long fascination with the work of J. H. Michell, a distinguished Australian mathematician located at the University of Melbourne from 1890 to 1928, who was elected to the Royal Society of London in 1902. Michell published relatively few articles but these included his now famous 1898 article (A) on the wave resistance of thin ships in deep water. Ernie gave an historical account of this paper in (100) and pointed out that this was an exact solution within the framework of linearized water-wave theory. Michell's remarkable result was ignored for nearly 25 years, but after it was rediscovered by the famous British applied mathematician T. H. Havelock, it has remained a benchmark for practical calculation of wave resistance to the present day. Although Michell's work is now remembered for his deep-water wave resistance integral formula, Ernie pointed out in (53, 100) that Michell's paper also contains some remarkable insights into wave resistance in shallow water that presage much subsequent work. Michell's integral was a theme Ernie returned to often, notably in his 2005 IUTAM paper (157) and in his 2008 ICTAM paper (184), which was his last international conference presentation. Wave resistance was a theme Ernie returned to often, notably in (99) where it was shown that there may be ships with zero wave drag for a submerged body, again in (144, 147, 161, 165) where he addressed the problem of how to minimize the wave resistance, and in the invited lecture (166) at the 2003 ICIAM conference in Sydney. Although most work, including Ernie's contributions, on waves generated by slender bodies is based on linearized theory, Ernie was always mindful of nonlinear effects. He examined these in detail in a numerical study (164), which showed that except for the occasional possibility of a wave-breaking event, the linearized theory worked rather well both qualitatively and quantitatively.

Much of Ernie's early work was based on linear water-wave theory, as was customary at that time due to a combination of insufficient computer power and a lack of experience with nonlinear techniques. An important exception was (8), where Ernie analysed the flow of an infinitely deep fluid past a submerged circular cylinder. In the linearized theory the outcome is the generation of stationary lee waves, from which the wave resistance can be calculated. Ernie carried this calculation forward to account for the next-order nonlinear effects, and in doing so corrected and improved several previous attempts on this problem. One finding that attracted much interest was the prediction of the possibility of jets emerging from the free surface. An important finding of this paper was that the common practice of representing fully and partially submerged obstacles by source distributions, while valid in linearized theory, was likely to fail in even a weakly nonlinear theory. Another 'water-wave' paper in this period is the much-cited (21) which, again using linearized wave theory, provides a general and practical technique for calculating the response of a harbour to an incident wave field. A related topic is wave diffraction through a small gap, and in (27, 33) this problem is addressed, again using the method of matched asymptotic expansions. The articles (30, 49) are a rare excursion by Ernie into water waves propagating over a non-uniform bottom, motivated in (30) by the problem of tsunami generation. In article (38) Ernie examined how viscous wave damping affected ship wave resistance and Michell's integral. Other instances of Ernie's wide-ranging interests in fluid mechanics is article (34), where he used asymptotic techniques to analyse heat flux meters and make optimal design suggestions, and the highly-cited (48) where he used asymptotic theories for thin jets to analyse the shape of a free jet of water emerging from a nozzle, the 'hose-pipe' problem. Article (54), another highly-cited paper, examines several nonlinear free-surface boundary-value problems in the low-speed limit, such as the wave-like flow behind a semi-infinite body, and shows how to 'sum' divergent series using iterative nonlinear transforms.

The nonlinear theory of water waves is often described by potential flow in the fluid domain, where the governing equation is the linear Laplace equation. The nonlinearity resides in the free surface boundary conditions, which to this day have proven a source of rich dynamics but remain analytically very difficult to handle except by perturbation expansions. It has been known for a long time that solving the Laplace equation with integral expressions leads to nonlinear integral equations for the motion of the free surface. Although this reduction in the number of degrees of freedom is valuable, the nonlinear integral equations usually require numerical evaluation, and it was not until the 1980s that computer power developed sufficiently for this to be a useful approach. In two spatial dimensions, conformal mapping techniques can also be used and, when combined with numerical solutions of the resulting integral equations, these turned out to be very powerful methods. Ernie was in the forefront of this approach and wrote several pioneering articles, beginning with the highly-cited (84) and followed by (89, 90, 91) setting the tone for this line of research which remains very active today. In article (94) Ernie revisited the hose-pipe problem, that is the water jet emerging from a hole in a wall. Using numerical methods on this highly nonlinear problem, Ernie showed that a smooth solution existed only if the jet speed at exit was sufficiently strong, and found the lower bound for this speed. Article (95) examined the nonlinear waves on the air-water interface caused by a moving hovercraft, followed in (125, 126) by the calculation of nonlinear ship waves, where a particular focus was on finding those ship hull shapes that reduce the amplitude of he emitted waves, and hence the wave resistance. Article (116) examines the generation of a breaking splashless wave by the impact of stream into a body of stagnant water, and it is shown that there is a unique speed which allows for such a solution. Article (121) examines the intersection of a steady free-surface flow with a vertical wall, and again uses conformal mapping and numerical methods to show that the angle of intersection can only be 180°, 120° or 90°, with associated limits on the allowed speed of the flow. Article (122) extends this conformal mapping technique to a class of flows containing recirculation regions with constant but non-zero vorticity. Another novel application was article (134) which used an inverse procedure to find ship bow shapes that can produce a splash-free bow flow. An interesting variation on the 'jet' problem was examined in (152) where the impact of a flow on to a barrier created both a forward and a backward jet.

As well as his main interests in ship hydrodynamics and water waves, Ernie had a major interest in low-Reynolds-number flows, that is, flows where viscosity dominates. His first foray into this area was the short note (14) on the self-propulsion of microorganisms, where he developed a model introduced by G. I. Taylor of a doubly-infinite flexible but inextensible sheet, propelling itself by small transverse oscillations. Ernie took account of fluid inertia, thus extending Taylor's analysis and correcting some earlier work, and showed that the propulsion speed is reduced. This was followed by (19) which examines the unsteady flow of a viscous fluid from a small hole in a wall, a situation of physiological interest. The linearized problem was solved exactly leading to a complicated integral expression that was then, in an approach typical of Ernie's style, evaluated asymptotically and numerically. In (18) Ernie examined the small oscillations caused an oscillating cylinder in a viscous fluid; although motivated here by issues concerning bilge keels in ships, the problem has general interest. Flow through small holes was again taken up in (44), which although formally an expository article also contains several new results. Ernie's interest in bio-fluid mechanics continued in 1971 with the article (31). In article (127) Ernie examined the low-Reynolds-number flow over a wavy wall, using a similar approach to that in (14) but now with the aim of addressing the problem of possible slip at a rough boundary, showing once again Ernie's ability to bring fresh and novel insights to much-studied and difficult problems.

A relatively new field in fluid mechanics is the dynamics of thin films with a free surface, where the principal balance is often between surface tension and viscosity, leading to some highly complex flows. This field is driven by industrial applications such as coating, drying and wetting, liquid crystals, polymers and complex fluids. Ernie was an early contributor to this field and his articles (103, 106) are his most highly-cited papers. Article (103) deals with the asymptotic theory of a third-order nonlinear ordinary differential equation, found to be a canonical model for contact-line and slip problems in a wide variety of physical contexts. Using a combination of numerical solutions and matched asymptotic expansions, the article describes the unravelling of the flow near the contact line and demonstrates the extreme sensitivity to the system parameters in this limit. Articles (106, 108) deal with the canonical 'raindrop' problem, that is a liquid drop draining down a vertical wall under gravity. The main difficulty in this problem is the contact line, as the classical 'no-slip' boundary condition fails to predict the advance of the contact line down the wall. This issue has not been completely resolved at the present time, and in (106) it was assumed that there was an infinitesimally thin liquid layer ahead of the drop, an assumption for which there is some experimental evidence. Using a combination of careful numerical simulations and delicate asymptotic analyses, Ernie and his collaborators showed that consistent and physically useful solutions could be obtained. A companion article (108) examined the alternative hypothesis that the contact line does not move, but instead the upper portion of the drop drains leading to a steady-state with a contact angle determined by the solution, that is, it is not prescribed in advance. Article (118) examined the problem when an upward flow of air maintains a thin liquid film on a plane wall against gravity, while the companion article (119) examined the waves that might form on the thin film. The problem was reduced using lubrication theory to a nonlinear singular integro-differential equation that was solved numerically and asymptotically to obtain the solutions. These results were reviewed and extended in (120). Articles (133, 139) considered another kind of 'thin film' problem, namely the slow deformation of a very viscous liquid bridge suspended between two vertical walls. Then articles (153, 168, 187) considered the related problem of a very viscous liquid drop hanging beneath a fixed wall. These works illustrate both Ernie's capacity to combine delicate asymptotic analysis with careful computing, and his continuing fascination with 'every-day' observable fluid flows that nevertheless present a major scientific challenge.

Ernie was a consummate expositor, as all his articles and his conference presentations show, and his talents were put to good use in the textbook on chaos theory for school children (109) that he co-authored with Neville de Mestre. After his formal retirement, Ernie became interested in the famous and still unsolved Riemann's hypothesis, namely that all zeros of the Riemann-zeta function lie on a certain straight line in the complex plane. The articles (173, 175, 176, 183) deal with related issues, while his articles (181, 182) deal with the hypothesis itself. His work had begun to attract some international interest (see (F)), on account of the novelty and potential of his approach to this problem.

Ernie Tuck was one of Australia's most outstanding applied mathematicians. He will be remembered for his ability to find interesting and challenging problems in fluid flows and water waves, often motivated by personal curiosity and observation, and then to tackle them with apparently simple but incisive and elegant analysis. His international reputation was established early in his career by his seminal and compelling theoretical analyses on the wave resistance of slender ships and wave interaction with obstacles, and he was and remains today a leading authority on water waves and ship hydrodynamics. As his career progressed he expanded his interests to other areas in fluid mechanics, where again he had the insight and the courage to tackle the fundamental issues of the problem being addressed. He was an outstanding expositor in both written and spoken formats, and will be fondly remembered by his former students and his many colleagues as a brilliant scientist and an enthusiastic and caring person.

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