# Anthony Edward Perry 1937–2001

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Tony Perry was one of Australia's most outstanding researchers in fluid mechanics, particularly in the study of turbulent fluid motion. He was a gifted experimentalist who advanced the techniques of hot-wire anemometry and quantitative flow visualization to make measurements of unparalleled accuracy to answer fundamental scaling questions. He also made seminal theoretical contributions to the physical modelling of wall-bounded turbulence, and pioneered flow topology approaches for the classification and description of fluid motions. He was a gifted lecturer, devoted supervisor to twenty PhD students, and a passionate and enthusiastic influence on numerous colleagues around the world.

Anthony ('Tony') Edward Perry was born on 19 February 1937 at his family home in Newport, a suburb of Melbourne, to Anthony William Perry and Everald Marjory (née Barlow) Perry (subsequently Vines, Stephens). He had a younger brother, Lionel. Tony's father was born in New Zealand but moved to Australia at a young age and resided principally in Inglewood, Victoria; he was a mechanical engineer working at Australian Paper Manufacturers.

Tony's childhood was disrupted with the divorce of his parents when he was six years old. His mother remarried, and had two more children, Diane and Leonard. Her new husband was not supportive of scholarly pursuits and consequently Tony's educational path was not a conventional one. He moved from De LaSalle College in Malvern to St Joseph's Technical College in Collingwood, to full-time employment at Imperial Chemical Industries in Yarraville at age 14. Although working full-time, Tony developed a strong interest in engineering and mathematics and enrolled as an evening student at Royal Melbourne Technical College (now RMIT) for a Diploma in Mechanical Engineering. He completed the diploma course in two years, which had never been done before by a part-time student. His excellent grades allowed him to enrol as a third-year 'block-exemption' student at the University of Melbourne in Mechanical Engineering.

He graduated in 1960, completed a Master of Engineering Science degree in 1962 with a thesis on 'Hydrodynamic Roughness and its Effect on Turbulent Boundary Layers', and in the same year joined the staff of the University of Melbourne as an Assistant Lecturer. He was promoted to Lecturer in 1965. He received his PhD in 1966 for a study called 'Some Aspects of Turbulent Shear Flow', and then took up a post-doctoral fellowship at Harvard University in 1966–67 before returning to the University of Melbourne. He was promoted to Senior Lecturer in 1969, and to Reader in 1972. In 1984 he was appointed to a personal chair (professorship) in Mechanical and Industrial Engineering in recognition of his outstanding contributions to research. He served as the Head of the Mechanical and Manufacturing Engineering Department from 1 January 1990 to 31 December 1991.

On 10 January 1968, Tony married Lorna Dorothy Tarrant. They spent their honeymoon visiting the University of New South Wales and the University of Queensland and attending a conference at the Australian Atomic Energy Commission's facility at Lucas Heights near Sydney, before taking up residence at Melbourne's Ormond College, where Tony was a tutor. It was clear to Lorna from this beginning that Tony's work was going to play a significant part in their future! They had four children: Anthony (1968), Jodie (1970), Alexander (1977) and Kimberlea (1983), and later four grandchildren. Lorna grew up in Melbourne but was born in China where her parents, Rev. George and Dorothy Tarrant, were Christian missionaries. Tony's older son, Anthony David (né Perry) Bloam, graduated with a degree in Mechanical Engineering from the same department as his father and went on to receive a PhD from the California Institute of Technology (Caltech) in pure mathematics.

## Honours

In 1979, Tony was made a Fellow of the Institution of Engineers, Australia, and in 1985 was elected a Fellow of the Australian Academy of Science. In 1992 he was a Sherman Fairchild Distinguished Scholar at Caltech. In 1996 he held the Clark B. Millikan Chair of Aeronautics for distinguished visitors at Caltech, and in 1999 he held a Rothschild Visiting Professorship at the Isaac Newton Institute for Mathematical Sciences at the University of Cambridge, UK. In 1998 he was elected a Fellow of the American Physical Society with a citation reading: 'For physical insights into the behavior of turbulence, structure-based modeling approaches, elegant use of scaling arguments and inspirational teaching'. This citation succinctly and accurately describes Tony's successful career as a researcher and educator. Since his passing, Tony has been honoured by his peers with editorials

devoted to him in the *Journal of Fluids and Structures* and *Experimental, Thermal and Fluid Science*. In addition, two international symposia have been held in his honour, one in Adelaide in 2001, the other in Kingston, Ontario, Canada, in 2004.

## Early Years at Melbourne

Once enrolled at the University of Melbourne, Tony thrived in his courses, particularly enjoying those given by Dr Franz Laszlo on solid mechanics. Laszlo had a thick Hungarian accent and most students found his lectures very difficult to follow. Tony on the other hand had a great appreciation for the deep mathematical insights Laszlo's courses would explore. This strong mathematical grounding greatly complemented Tony's instinctive appreciation for geometry, and these interests characterized well his unique approach to tackling complex problems.

Tony first met Hans G. Hornung (now Emeritus C. L. 'Kelly' Johnson Professor of Aeronautics and Emeritus Director of the Graduate Aeronautical Laboratories of the California Institute of Technology) when they were undergraduate classmates, and they became lifelong friends. Upon completion of their degrees in 1960, Tony and Hans started postgraduate research together in the fluids group at Melbourne led by Peter N. Joubert.

Peter Joubert had been a Second World War fighter pilot and, after demobilization from the RAAF, had studied aeronautical engineering at the University of Sydney. He was appointed a lecturer in mechanical engineering at the University of Melbourne in 1953, specializing in fluid mechanics. He recognized, very early on, the importance of fundamental research in fluid dynamics and stressed the importance of publishing in quality journals. He proved to be the perfect mentor for Tony.

Tony, Hans and a fellow student, Errol R. Hoffman, worked closely together in the

'yellow wind tunnel' (as it is still called today), a large recirculating wind tunnel built by Peter Joubert. The tunnel was housed in the back part of a ramshackle tin shed known as the 'Brown Coal Laboratory', and the laboratory had a particularly gritty feel about it. Each had separate projects for their Master's degrees but they worked together as a team, designing and overseeing the fabrication of the equipment that they would share. Tony was responsible for designing a new closed working section for the wind tunnel and a combined Pitot and yaw probe; Hornung designed a traversing system for the probe, capable of an impressive five degrees of freedom, two of which were controlled remotely; and Hoffman designed the traverse rails and bridge.

During this period, Joubert's group was visited by G. K. Batchelor and A. A. Townsend who were world-leading figures in fluid mechanics from Cambridge. Both were also Australians and graduates from the University of Melbourne and they took great interest in the careful turbulence experiments being conducted by Joubert's students. George Batchelor was the founding editor of the *Journal of Fluid Mechanics* (*JFM*), which upon its publication in 1956 almost immediately became the leading journal in the field. Alan Townsend and George Batchelor had both worked at the Aeronautical Research Laboratories at Fishermen's Bend in Melbourne during the war and in 1945 had moved (or in Townsend's case returned) to the Cavendish Laboratory in Cambridge to be PhD students of G. I. Taylor. The visits by Batchelor and Townsend and the fruitful discussions that ensued had a great impact on Tony and the Melbourne fluids group as a whole. With Batchelor's encouragement, Hornung, Hoffman and Perry each submitted papers to *JFM* (co-authored with their supervisor Peter Joubert), and all were published promptly. This affirmed the quality of the work being done at Melbourne and the

group (later to be led by Tony) did not look back from then on.

## Overview of Research Contributions

Tony's early research encompassed several themes that would stay with and guide him throughout his career. He was strongly influenced by the similarity arguments, based on dimensional analysis and scaling, advanced by Prandtl, von Kármán, Millikan, Coles, Hama and Clauser. The first ten years or so of his research were focused on using these tools, combined with careful experiments, to understand the behaviour of the mean-velocity profile in wall-bounded turbulent flows on smooth and rough walls. This included considering boundary layers with varying streamwise adverse pressure gradient (3, 8, 9), and three-dimensionality in the mean (6). Tony's first paper in *JFM* (3) was based on his Master's thesis (2) and it addressed the effects of hydrodynamic roughness on wall turbulence, a challenging subject that he would continue to revisit for the remainder of his life. His Master's thesis is remarkable for its depth of thought on such a difficult problem. It is also the first place where Tony used the terminology of '$k$'-type and '$d$'-type roughness to distinguish the different responses of turbulent wall-bounded flows (boundary layers, pipes and channels) to a specific pattern of roughness. This nomenclature later became the standard in the field after it was published in *JFM* (12). As Townsend (1976) says:

> two kinds of roughness behaviour can be distinguished, depending on whether the relevant fields of velocity and pressure are specified by motion in the equilibrium layer alone or by motions outside. The first kind, '$k$' type roughness in the nomenclature of Perry, Schofield & Joubert (1969), is shown by surfaces with irregular corrugations and protuberances, e.g. sandpaper (that is, for $k$-type roughness the roughness length scales with wall variables) ... The second type of roughness behaviour is found when the shape of the roughness elements is such

that the flow around them is almost unstable and can be disturbed violently by small fluctuations of large scale in the outside flow. (In this) '$d$' type behaviour, the roughness length becomes a fixed fraction of the channel width (that is, in $d$-type roughness the roughness length scales with the diameter).

Tony continued to investigate roughness throughout his career, including studies in turbulent boundary layers with his students Jun De Li (89) and Kong Loong Lim (78). Tony also built two pipe experiments to study smooth and rough flows (one with Chris Abell and the other with Simon Henbest). One of the last papers he wrote (133) also discussed roughness effects, this time in the Superpipe experiment at Princeton.

Tony's early work on the mean-velocity behaviour in wall turbulence was just the beginning. Ultimately he wanted to solve the problem fully by understanding the physical mechanisms of turbulent boundary layers and how one could use this to predict their behaviour using the Navier-Stokes and continuity equations. He believed strongly in starting his research with the equations of motion, and would always look for ways to better understand what 'they were saying'. Experimentation was an integral part of his approach to research. Tony would often describe the wind tunnel as 'nature's own computer'.

After returning to Melbourne from Harvard in 1967, Tony collaborated regularly with his colleagues, Bill Schofield (later Director, Aeronautical Research Laboratories, Defence Science and Technology Organization, Australia) and Andrew Samuel (later Professor at the University of Melbourne), and at the same time set about establishing a first-class experimental research programme with turbulence measurements at its core. The majority of Tony's work from then on was with his PhD students and postdoctoral fellows. Tony's first graduate student was Graham Morrison and his PhD thesis topic changed from a study of

pipe flow turbulence to an in-depth investigation of hot-wire anemometry. When Tony started to study the turbulent fluctuations in wall-bounded flows, it rapidly became clear to him that their scaling behaviour could only be understood by obtaining a database consisting of accurate measurements. This led to what he called a 'Royal Commission on Hot-Wire Anemometry'; that is, a top-to-bottom re-examination of the performance of the sensors and the circuitry used in hot-wire anemometry, and the implementation and application of the technique. These hot-wire investigations also became the focus for Lex Smits, who in addition investigated laser-Doppler anemometry methods. Together with his students, Tony developed a deep understanding of the system performance of constant-temperature and constant-current hot wire systems and perfected a method of dynamic calibration, which was more accurate than previous calibration schemes.

Although he changed hot-wire anemometry from an art to a science, he never thought of it as an end in itself. It was always just a tool, and he felt strongly that sometimes a craftsman needed to examine his tools. Sometimes that might take years, but if there was a need for careful measurements, then it had to be done. If it led to sixteen refereed papers (five in *JFM*: 14–17, 35) and a major book (52), well that was fine, but it was always understood that it was just a warming-up exercise for the real job, which was to understand turbulence better.

Even as he was starting his work in hot-wire anemometry, another of his students, Bruce Fairlie, began studying separated flows. The characteristic flow patterns observed on the wall inspired Tony to take an interest in flow topology. In subsequent years, Tony almost single-handedly reintroduced the tools and language of topology into fluid mechanics. His first paper in this field, and perhaps the most seminal of all his publications, was 'Critical points in flow

patterns', written with Bruce Fairlie and published in a relatively obscure journal, *Advances in Geophysics*, in 1974 (24). Tony later applied the concepts of topology in all his descriptions of eddying motions, and the *p-q* chart defining the various eddy types (nodes, saddles, complex eigenvalue critical points and their degenerate forms) became his trademark. A review paper with Min Seong Chong (73) elegantly summarizes the work, and should be required reading for all students in fluid mechanics.

Min Chong had been a PhD student in combustion at Melbourne and when he graduated in 1977 he joined Tony as a post-doctoral fellow. He continued to work with Tony in a remarkable and productive collaboration that lasted until Tony's death. During that period, Min was appointed to the staff in 1987, and became Professor (personal chair) in 2003. Tony often called him 'my intellectual bodyguard'. They worked together on all aspects of turbulence, topology and teaching. Their travels together often achieved legendary proportions as they negotiated foreign languages, customs and immigration officials, even bemused police officers.

Tony's interest in flow topology strongly influenced the PhD theses of Jon Watmuff and Tee-Tai Lim. Jon Watmuff had spent considerable time designing and constructing what, at that time, was the world's largest flying hot-wire. This was an impressive facility that overcame the limitations of using hot-wire anemometers in flows with very high turbulence intensity or in separated or reverse-flow conditions. It allowed phase-averaged wake structures to be quantified with a measurement technique for the first time (50, 61). Tee-Tai Lim had begun his graduate research on laser-Doppler methods but changed this overnight after Tony and he observed the beautiful smoke patterns being formed in a laminar buoyant jet issuing from a circular nozzle. The flow visualizations that resulted and their topological analysis became the basis of

several high-impact papers (44, 51, 54), and included the making of the movie 'Eddies in Captivity' that was sold to many institutions around the world and is still an inspiration to watch. Tee-Tai Lim went on to work at NASA's Ames Research Center at Moffett Field, California, but after two years returned to Melbourne and worked as a postdoc in Tony's group for several years. Tony continued his interest in flow topology throughout the 1980s. He used it as a way of developing a new understanding of a variety of wall-bounded as well as free-shear flows (63, 75), working with subsequent students including David Tan, Eng-Waa Teh, Jennifer Anderson and Tom Steiner.

Tony's interest in understanding turbulence, his commitment to obtaining accurate turbulence data and his abiding love of flow topology came together in what may be his most influential contribution to fluid mechanics: an eddy-based turbulence model. Tony had informally published some preliminary work as early as 1979, but the complete concept first made its appearance in a classic publication with Min Chong, 'On the mechanism of wall turbulence', published in *JFM* in 1982 (53). Here, wall-bounded turbulence was modeled as a series of hierarchies of attached eddies—a concept first advanced by Townsend in 1976. The attached eddies had a characteristic $\Lambda$ shape, inclined downstream at 45°, as inspired by the 'horseshoe' eddies observed by Theodorson (1952). Each hierarchy consisted of a distribution of eddy sizes and each hierarchy was, on average, twice the size of the previous hierarchy, with half the number. By assuming that the characteristic velocity scale of the circulation contained in each eddy was the friction velocity, the ensemble-averaged velocity field of the eddies yielded the logarithmic velocity distribution for the mean flow, as required, and the turbulence distribution in spectral and physical space. Tony and Min had built, on the foundations laid by Townsend, the first turbulence model that incorporated the

complete physics of the coherent structures observed in wall-bounded turbulence.

The Perry & Chong attached-eddy model was later refined by Perry & Marusic (112, 113) to model the complete turbulence field, given only the mean-velocity information in flows with and without pressure gradients. This relied on using equations of motions to obtain an algebraic expression linking the Reynolds shear-stress to the mean velocity, which had not been done before without simplifying assumptions about the evolution behaviour of the boundary layer. The paper on the mechanism of wall turbulence also modeled convective heat-transfer effects, which Tony had earlier studied experimentally with his student Peter Hoffmann (28, 33). Modeling turbulence with coherent vortex structures was extended to flows with co-flowing jets with Tim Nickels (119), building on the previous flow-topology work in free shear flows. This includes studies with Richard Kelso and Tee-Tai Lim (118, 129), where details of the underlying flow topology of cross-flowing jets were revealed for the first time with careful flying hot-wire measurements and beautiful water-channel-based flow visualizations (93, 122).

The original motivation for the attached-eddy model stemmed from a desire to understand the correct dimensionless scaling for the turbulence intensities in wall turbulence, and therefore to predict how they would be affected by changing Reynolds number. For engineering predictions, this is critical as it allows laboratory-based low-Reynolds-number experimental data to be scaled up to the high Reynolds numbers found in most practical applications (for example, in the boundary layers found on the wings and fuselage of large aeroplanes, or in pipes that transfer oil or water over long distances). The original experiments that Tony carried out for turbulence intensities were in pipe-flow facilities. The first was with Chris Abell (25,

29), and then with Simon Henbest (72) in a pipe of similar diameter but now with a length of 400 diameters, just so Tony could be sure that entrance effects were negligible. Tony continued to investigate the scaling laws of pipe-flow turbulence over many years, starting with the experimental results at Melbourne and later the Princeton Superpipe results with Lex Smits and Mark Zagarola (127). The study of turbulence intensities and their associated spectra was extended to boundary layers, with studies in zero-pressure-gradient flows by Kong Loong Lim, Jun De Li, Salah Hafez and Mesbah Uddin (78, 99, 124). Tony commissioned a series of other studies in flows with pressure gradients. One of these cases was an attempt to achieve ideal 'sink flow'. Sink flow consists of flow between two straight plates, and theoretically represents the only smooth-wall boundary-layer flow that reduces to true equilibrium (Rotta 1962). That is, complete similarity exists where the boundary-layer profiles and all statistics become streamwise invariant when normalized by only one length and one velocity scale. While this had been hypothesized, it had never previously been shown experimentally. Tony achieved this milestone, and the paper was published with Malcolm Jones (who conducted the experiments) and Marusic in 2001 (132).

## Tony's Travels and Interactions

Tony's career in many ways highlights the benefits and importance of sabbaticals and study leave for academic researchers. During his career Tony often travelled for extended periods and always returned with a renewed vigour and full of new and creative ideas.

During his career, he spent extensive periods of time at Caltech, Stanford, Princeton, NASA Ames, Harvard, Göttingen and Cambridge. He was a frequent visitor to Stanford and spent three summers there as a visiting scholar at the Center for Turbulence

Research (CTR) in 1990, 1992 and 1996. The CTR collaborations resulted in several papers with colleagues at NASA Ames and Stanford (86, 87, 100, 111, 117, 128) and led to lasting collaborations with Brian Cantwell and Julio Soria. Tony's visits to Cambridge were also pivotal to his career as it was there that he visited Alan Townsend (who also visited Melbourne regularly). Cambridge was also the place where Tony first saw M. R. ('Mac') Head's wind-tunnel visualization results that had a significant influence on the 'mechanism of wall turbulence' paper with Chong (53).

Aspects of Tony's research were strongly shaped by his sabbatical visit to Caltech in 1973, where he worked with Donald E. Coles and his then PhD student Brian J. Cantwell. The visit was mutually beneficial for several reasons. Tony brought his hot-wire circuit design to the Caltech group, allowing them to build and analyse their own anemometers for the first time, and he also introduced Brian Cantwell to dynamical systems theory applied to fluid flow patterns, an area in which Cantwell later made seminal contributions. From Tony's perspective, his visit to Caltech introduced him to digital data acquisition, an area in which Don Coles was a pioneer, and this strongly influenced Tony's approach to experiments thereafter. Another important influence on Tony was the work Coles and Cantwell were doing with a new device called the 'flying hot-wire' capable of making measurements in regions of very high turbulence intensity or reverse flow. Conventional hot-wires could not do this since the heat-transfer principles on which they are based assume a nominal direction of the flow that cannot extend a critical incident-velocity vector angle. By moving ('flying') the wire with a large enough and known forward velocity, the incident angle for even a reverse flow could be resolved. The Caltech flying hot-wire was based on a whirling-arm design, providing measurements along a circular arc. Tony was interested in using the same principle but for measurements over an extended streamwise distance, and upon his return to Melbourne made this the PhD topic of Jon Watmuff. The result was the Melbourne flying hot-wire, which could move a wire at speeds up to 5 m/s over a 3 m distance (61). This was achieved using an ingenious mechanism and planar air-bearings. A later and new facility (built by Richard Kelso) extended the operation to over 8 m with speeds up to 10 m/s (104). These flying hot-wires enabled unique turbulence measurements to be carried out in a range of flows (and were central to the PhD experimental studies of Watmuff, Steiner, Kong-Loong Lim, Li, Marusic, Kelso and Nickels).

Tony would often comment that while he only spent nine months at Harvard they were perhaps the most beneficial of his career. It was there that he was first introduced to pipe flows by Richard E. Kronauer, and to dynamical systems theory, which strongly influenced his future work on flow topology and boundary layer evolution. The work on pipe flow was the start of his investigations into the structure and scaling of wall turbulence, for which he is now perhaps best known. The topic of boundary layer evolution was also one that he worked on throughout most of his career. Upon his return to Melbourne, Tony began a theoretical investigation of how wall turbulence evolves over streamwise distance in the presence of arbitrary pressure gradients, and this led to a manuscript in 1968 that was never published.

Tony returned to this problem in 1992 while on sabbatical at Caltech and having regular discussions with Don Coles. He developed the missing algebraic expressions required to advance the calculations in boundary layers, which had eluded him previously, and upon returning to Melbourne continued to work on this problem with his then postdoc, Marusic, and his PhD student Malcolm Jones. The work that Tony had started in 1967 was finally

completed during his last days (literally in his hospital bed). The paper was co-authored with Marusic and Jones and was published posthumously in 2002 (134).

Another important collaborator of Tony's was his good friend Hans Hornung, whom Tony visited regularly in Göttingen and later at Caltech. In 1984, Tony spent an extended period visiting Hans (at that time, Director of the Institute for Experimental Fluid Mechanics of the Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt (DFVLR)), and they developed a rigorous description for separated flows using topological tools and the concept of vortex skeletons.

An important aspect of Tony's research programme was having a critical mass of graduate students and postdoctoral researchers working in the laboratory at one time. This was very effective in passing down knowledge from one group of students to the next. Most of Tony's postdocs stayed for several years, mainly because the work was so interesting. A list of the postdocs who worked for Tony for more than one year includes Min Chong (1977–87), Tee-Tai Lim (1984–93), Ivan Marusic (1992–98) and Tim Nickels (1993–96). Tony also had a strong relationship with the technical staff, whom he regarded as critical for a successful experimental programme. Derek Jaquest, the lead technician in the Walter Basset Aerodynamics Laboratory, worked with Tony for over thirty years.

**Tony's Way**

It would be inappropriate to write a memoir on Tony Perry and not mention his personal characteristics that made him a pleasure to work with. Tony was both intensely serious and self-mocking. This was true of all he did: he gave his soul to the study of turbulence, but he could always see it in perspective and laugh at it all. About the only thing apart from his family that he took absolutely seriously was his allegiance to the Collingwood Football Club, where he suffered mightily along with the club in its misfortunes for many years.

Tony's style for tackling difficult problems was intriguing and his approach always demonstrated his total dedication to the subject. The problems Tony chose to work on were difficult ones that invariably involved an ever-increasing mosaic of complexity depending on how deeply one chose to look at them. While always passionate, Tony's approach was consistently careful and patient—he believed in doing things properly, otherwise they were not worth doing. Also, while Tony had an uncanny mastery of the early literature of his topics of interest, he would avoid being 'distracted' by the literature once he embarked on a strategy for solving a problem. This reflected his confidence in his ability to think things through independently. Similarly, Tony would always derive a concept or theorem from scratch if he felt that it was central to his approach, rather than rely on the work of others. During his career Tony very much set his terms for doing research and was focused on only publishing significant papers and only submitting them to the best journals. He also avoided distractions that would take him away from the pace that he felt was required for creative and rewarding output. This included not applying for funding beyond what he felt was minimally needed. Thus he rarely held more than one modest grant at a time, and while this was not always appreciated by his university's administrators, he felt it was the correct level in order to carry out the highest calibre of work.

Working as Tony's student was always an adventure fuelled by Tony's infectious enthusiasm. He demanded much from his students but was also very devoted to them. It was perhaps not a surprise that his first book on hot-wire anemometry was dedicated to his students. Tony also had a wealth of aphorisms that he impressed on his students, as in 'you can't steer a stationary

car' and 'the only way to avoid a mis-take is never to do anything'. He also had some rousing battle cries: 'We can do this: we don't even have to have a reason!' and 'We have the technology!' Tony and Hans also often used the adjective 'passion-drenched' (lifted from a cartoon of the time) to describe a scientific result.

Tony's passion for science was reflected in his approach to life. One of Tony's favourite poems, which he displayed on the back of his office door for many years, was 'First Fig' by the American poet, Edna St Vincent Millay:

> My candle burns at both ends;
> It will not last the night;
> But ah, my foes, and oh, my friends
> It gives a lovely light!

In many ways this was the way Tony chose to live his life. Tony's last few years were made difficult by complications due to emphysema and other respiratory ailments, but these did not dampen his enthusiasm. He passed away on 3 January 2001.

## Acknowledgments

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