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Robert William Bilger 1935–2015

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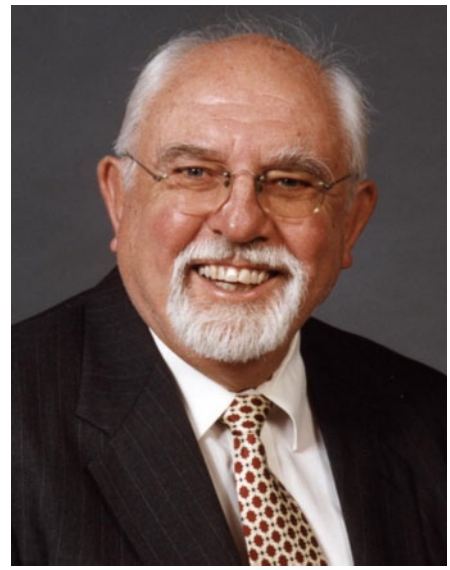
Robert William Bilger was born in Rustenburg, in the North-west Province of South Africa on 22 April 1935 and died in Sydney, New South Wales, on 2 October 2015. He had a distinguished academic career at the University of Sydney. His most important contribution to combustion research was the pioneering of conditional moment closure methods as a reliable predictive tool for turbulent reacting flows. He also made significant contributions to environmental flows and combustion chemistry.

Early Days



Robert (Bob) Bilger was born on 22 April 1935 in Rustenburg, North-west Province, South Africa (Fig. 1). His father, Ernest Victor Bilger was born in England on 19 August 1901 (died 1980) and as a purser on ships, survived being torpedoed in 1916 and two subsequent years as a prisoner-of-war. His mother was Lilian Marjorie Irvine (née Smith), born 15 December 1910 in Johannesburg, South Africa. She died in 1990. Ernest and Lilian met on a voyage of the Orient Line ship *Orama* and married on 15 January 1932. A daughter (Frieda) was born in Kent, England on 24 January 1933. The family then moved to Rustenburg where they ran an orange grove. Bob and brother Jonathan Victor (born 1936, called Jock) were born in Rustenburg. Due to disappointing prices for oranges, the family moved to Auckland, New Zealand in March 1939, sailing on *Dominion Monarch*. Bob spent his formative years in Auckland; demonstrating academic distinction at Orakei Primary School and then at Auckland Grammar School where he was Old Boy 1948 and was Dux of his class in 1952. He went on to graduate with a BSc in mathematics and a BEng with first-class Honours and a University Medal from the University of New Zealand (Auckland University College) in 1957 (Fig. 2).

As a result of his academic success and also his sporting activities in rugby, sailing and rowing, he was awarded a Rhodes Scholarship (1957–60) to study at Oxford University (Exeter College) to read for his Doctor of Philosophy (DPhil) in engineering science. Travelling to England on the ship *Oronsay* he met Jill, his future wife. Jill Elizabeth Ann Herbert was the daughter of Lt Colonel Albert Royal Tasman Herbert and Ena Victoria née Priddle. Jill was born in Geelong, Victoria on 6 November 1936, and she married Bob at Oxford on 9 July 1960.

Bob's research topic at Oxford was fluid mechanics under the supervision of Professor Alexander Thom. Bob worked on aerodynamics, becoming an expert on how to measure pressure and speed in fluid flows. In December 1960 he submitted his DPhil thesis and then immediately moved to London to begin work with the Northern Research and Engineering

Corporation. The degree was conferred in 1961 and in the same year daughter Victoria was born (8 July). In 1967 Caroline (born 1966) became part of the Bilger family.

Consulting Engineer

Bob worked with the Northern Research in London (1960–2) and in Cambridge, Massachusetts (1962–4). The family sailed from the UK to the USA aboard *Queen Mary* in 1962 (Fig. 3). Bob wrote an article about his experience at Northern Research.[1] He explained that the firm's founder, Jack Rizika, invented a pump, funded its development with his life's savings, and eventually become rich. In the article Bob said: 'Working for one of these [small consulting] companies can be very stimulating'. In fact, it triggered his involvement in combustion, which then became one of his principal research interests.

Figure 1. Father, mother and baby Robert in 1936.

Figure 2. At graduation in Auckland 1957: B.Sc., B.E(NZ) First class honours and University Medal.

Bob was recruited in 1970 (while on leave from Sydney University) to be Technical Director at Handley-Page, a famous British aircraft firm. The firm went bankrupt after he had been there just a few months (not his fault!). Bob rejoined Northern Research in Cambridge, Massachusetts, albeit for a short stint. It was during this time that he visited the Tanners in Providence, Rhode Island. Roger and Elizabeth were renting a vast house with ten bedrooms, one of which was used for model trains and another as an indoor hockey rink. Later that year, the Bilgers returned to Sydney University via Salt Lake City, Utah where they attended the 13th Combustion Symposium, 23–29 August 1970.

Academic Life at the University of Sydney

Bob was appointed a senior lecturer in mechanical engineering at the University of Sydney in January 1965, and migrated to Australia with Jill and Victoria. They travelled to Sydney from the USA via Mexico, Tahiti and Auckland. Initially they rented a house in St Ives and then bought and

Figure 3. On *Queen Mary* en route from England to Cambridge, Massachusetts, USA, 1962.

Figure 4. Warrumbungles Excursion in 1965. (Back row: Roger Tanner, Jill Bilger, Bob Bilger, Bob Feik (Aero), Bob Antonia. Front row: Don Fraser, John Simmons). Photo: Don Fraser.

moved (in August 1965) into Trevalgan Place, St Ives. This home is on the edge of dense bushland and at least once was close to a bushfire zone. It remains the family home.

Life was relaxed in those days—a party of seven of us went camping in the Warrumbungles National Park in north-west New South Wales in 1965, a time when the Park was truly wild. Jill came, so did John Simmons and Bob Antonia, both of whom went on to have distinguished academic careers (Fig. 4).

Bob's first scientific paper, published in *Nature*, was concerned with draining a bathtub, addressing the question of which way the water swirls in the southern hemisphere.[2] This project was started by Lloyd Trefethen with encouragement from Professor Tom Fink when Lloyd was in Sydney on sabbatical leave in 1964/5 from Tufts University in Cambridge, Massachusetts. Lloyd was already famous for his work on surface tension phenomena, and he led us in a repeat of the experiments on the bathtub vortex that had recently been conducted by Ascher Shapiro at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts. After much careful design, a circular tank of some 2.4 m in diameter and 0.4 m depth was constructed and installed in one of the subterranean dungeons of the old Peter Nicol Russell Building (now called the Woolley Building).

These tests showed clearly that the water did swirl oppositely in the southern hemisphere. So the *Sydney Morning Herald* staff came along to report. Unfortunately, while uncovering the tub for the demonstration, Bob and Roger dipped the lid in the water and the swirl went down the plughole the wrong way! We got lots of publicity for this experiment—including a spot in *Time* magazine (Fig. 5).

Bob was promoted to Associate Professor in 1975 and one year later, he was appointed Professor of Mechanical Engineering in a newly established Chair. Bob has enriched both Sydney University and his profession through decades of service and consulting work, including seven years as Head of School.

One of his lasting achievements was a deep involvement in the establishment of the Warren Centre for Advanced Engineering. Set up as part of the celebrations of 100 years of Engineering at

Figure 5. Bob Bilger (centre) with Roger Tanner and Sam Luxton investigating the bathtub vortex in the southern hemisphere (1965).

the University of Sydney, the Centre was named after the first professor of engineering, William Henry Warren.[3] The Centre was not be a conventional academic research centre, but would 'co-operate with industry to promote excellence and innovation in all fields of engineering in Australia'. The funding was provided by industry and graduates, and the fund-raising target of $2 million was met under the able guidance of Keith Brown. Bob Bilger not only persuaded the Vice-Chancellor to support the concept, but Professor Williams also offered support of $50,000 a year for four years. The Senate of the University ratified the Centre constitution in November 1980. Bob was appointed as Interim Director and then as Director 1982–5. The Centre flourished under his directorship, and it continues to do excellent work.

After this busy period, Bob went on sabbatical leave (for the third time). Previously he had visited and made useful contacts at the University of California (at Berkeley and San Diego) and at the Sandia Laboratories in Livermore, California. This time he was awarded a Japan Society for the Promotion of Science (JSPS) Fellowship, and he and Jill set out for Japan on 3 May 1985 for a hectic six-week tour. They were met in Tokyo by Professor Tsuji of Saitama University. The Bilgers then flew to Akita airport in the north-west of Honshu and rented a car. They noticed the air pollution and the slow (~40 km/h) traffic. A typical day in Bob's diary reads: 'I woke at 3 am and wander around the hotel, write a letter to Tsuji and then when it is light at 5 am walk up to Old Castle.'[4] (He was always a fantastically early riser, and in later years early to bed, often by 7 pm). He endured raw egg for breakfast and found it difficult to sit at low tables for a long time with legs stretched out. He visited numerous laboratories on the tour—it must have been exhausting. In Sendai, Bob thought his talk about flames near extinction was 'at too advanced a level for most of the audience'. Importantly, he discovered in Japan the term mechatronics (essentially to do mainly with electro-mechanical robots), which was appropriate for the new courses then being introduced in mechanical

engineering at the University of Sydney. Hence we offer a degree in mechatronics, which is now embedded in the name of the school.

The rest of the leave was spent studying combustion at the Centre Nationale de la Recherche Scientifique (CNRS) in Rouen, in northern France, a city that had been famous for combustion incidents since the burning of Joan of Arc at the stake on 30 May 1431. Bob had another sabbatical leave at the University of California (Berkeley) and at the Sandia Laboratories in 1989. In between sabbaticals he travelled widely to conferences and laboratories in order to keep in touch with colleagues.

Bob's efforts to maintain contact with graduates led to the founding of the University of Sydney Mechanical Engineering Association (USMEA). He served as the President of the University of Sydney Association of Professors. In the 1970s, Bob served as the University's representative on the NSW Clean Air Advisory Committee. He played a leading role in the introduction of stringent industry controls on sulphur, hydrocarbon, oxides of nitrogen, fluoride, lead and asbestos emissions and also contributed to the successful adoption of advanced emission controls for motor vehicles.

In 1987 Bob was elected as a Fellow of the Australian Academy of Technological Sciences and Engineering (FTSE), which recognized his earlier work on combustion and environmentally related science and technology. As a climax to his outstanding work on combustion science, he was elected as a Fellow of the Australian Academy of Science (FAA) in 2003.

While Bob is mostly known for his outstanding contributions to combustion research, his interests were much broader and spanned the fields of fluid mechanics and environmental science. For example, with Professor M. J. Atkinson of the University of Hawaii, he wrote in 1992 an influential paper on the subject of phosphate uptake in coral reefs.[5] To investigate this subject they placed communities of reef organisms in the bottom of a flume, ~10 m long and 350 mm wide. The idea was to avoid the effects of surging waves on the rate of phosphate uptake. They found that uptake was significantly greater than estimates from engineering formulae. By May 2016 the paper had been cited 130 times in the ISI database.

In collaboration with John Kent (who was Bob's first PhD student and became Professor of Mechanical Engineering at the University of Sydney in 1998), Bob investigated vehicle emissions resulting from the Sydney driving patterns of cars. He also had a project on the burning of bagasse (sugarcane residue). As testimony to his breadth of interests, Bob obtained funding from the Australian Research Council to investigate the chemistry of photochemical smog. To this end, he has set up the world's largest smog chamber (Fig. 6). This was a large plastic bag that was used to study the chemistry of smog formation from the reactions of nitric oxide and ozone.

Bob remained in the Mechanical Engineering Department until his retirement in 2006. He was then awarded the title of Emeritus Professor and continued his work there.

Hobbies

As to Bob's hobbies, sailing was always a joy for him, and he was an excellent cook and host. He once bought a huge half-squid at the market, believing that a squid diet was the key to losing weight. However, it took so long to use up, albeit always well cooked, that it proved too much for Jill. There were moments of sheer comedy, one from 1973 when Bob came to a party given by the Tanners at Collaroy beach. That day Bob had acquired a desk and chair and had put them into an open trailer hitched to his car to take home. After the party he got Jill to drive home while he sat at the desk in the trailer enjoying the beautiful moonlit night.

Later Bob took up golf and played numerous games with Roger. Once, after a game, he bought a new set of clubs and ordered a new set of golf shoes. He wore size 14 shoes, which were not regularly stocked. Bob was always very competitive, and at golf he was no different. One day when he was out practicing by himself at the Gordon golf course he got into a sand bunker. He hit the ball a mighty wallop, it hit a projecting rock and flew back to hit him squarely between the eyes. Blood flowed everywhere and stitches were needed. A complaint to the club suggested they put more sand in the bunker, and they did. Golfing came to a sudden end in July 2006. After feeling 'woozy' at the end of a round he was

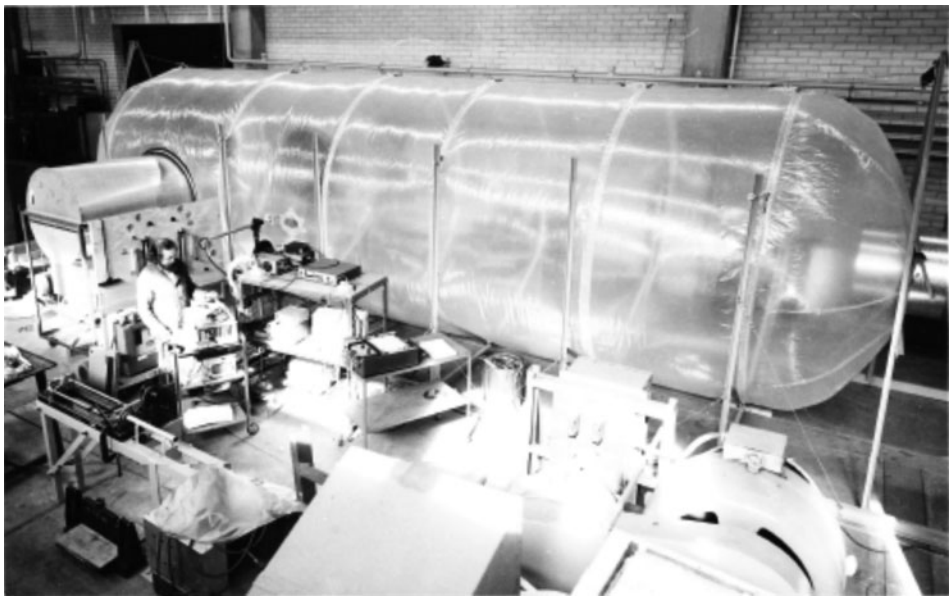


Figure 6. The turbulent smog chamber showing Dr Neil Mudford working the instruments; he provides a scale for the size of the balloon.

rushed into hospital for insertion of three stents into his arteries.

At his eightieth birthday celebratory lunch in May 2015, held at the Barranjoey House restaurant at Palm Beach, he seemed well and spoke well, but afterward he declined quickly. He is survived by his brother Jock, his wife Jill, daughters Victoria and Caroline, and grandchildren Elizabeth, Rose and Reece. His academic family is even larger with sixteen 'academic children', as he loved to refer to those who were privileged to study for PhDs under his tutelage, and many more 'academic grandchildren' for whom he cared just as much.

Research Achievements in Combustion and Chemical Reactions

Bob and his team at the University of Sydney contributed to several areas of applied combustion and chemical reaction research, which are briefly described here. Environmental pollution was a severe problem in Sydney and so a large applied research project on the formation and transport of photochemical oxidants in the Sydney air basin was carried out in the mid-1970s in association with Macquarie University and the NSW State Pollution Control Commission (SPCC). Dr Keith Post headed up the field measurements and Dr Greg Allen carried out work on computer modelling.

Interest in obtaining spatially and temporally resolved measurements in reacting turbulent flows led to the construction of a huge plastic bag (Fig. 6) in which mixing occurred between two air streams, one spiked with ozone and the other with nitric oxide. Hot-wire anemometry for measurement of two components of velocity together with a locally developed very fast chemiluminescent analyzer, provided time and space resolved measurements of mixing and turbulent fluxes. Drs Salah Ibrahim and Richard Brown produced ground-breaking PhDs on this experiment together with post-doctoral researchers Neil Mudford, Lars Saetran and Jun-De Li. The large bag earned several nicknames, and a television reporter dubbed the facility 'the world's largest condom'!

In association with John Kent, another large project on the pollutant emissions and fuel consumption of in-use motor vehicles was carried out in the early 1980s with funding from the National Energy Research and Development Corporation (NERDC). The interest in air

pollution from motor vehicles led Bob to initiate a project to develop a Driving Cycle for Sydney. Vehicle emissions in Australia were tested by the SPCC (State Pollution Control Commission) on a vehicle dynamometer over a driving cycle set by the Environmental Protection Agency in the USA. The thinking was that the cycle might not be representative of Australian city driving patterns so a vehicle was rigged with a 'fifth wheel' and a data logger and driven extensively throughout the city to record driving patterns. The data were condensed and a driving cycle was developed. This was subsequently used to test many vehicles in a dynamometer laboratory setup in the Mechanical Engineering Department. Volunteer and University vehicles were tested and a database was built up. It also led to development of a parametric model to predict vehicle emissions over any driving situations to be used as a tool for urban planning.

In addition, a truck was outfitted with instrumentation to sample air quality; several gas containers containing combustible gases were on board. The idea was to chase a parcel of polluted air through the city in order to record its chemical history. Whilst the venture was successful, the project came to an abrupt end when, just returning to the University campus, the gases ignited and burnt out the truck completely.

Other applied research projects conducted under Bob's supervision in the later 1980s include the burning of bagasse (waste from sugar milling) and the study of fire spread on conveyor belts in coal mines. The former project involved Bruce Lamb, seconded from CSR Ltd, to study the combustion of bagasse on sloping grates. The latter project used the fire gallery built by the NSW government at Londonderry in Western Sydney. Also, in the early 1990s a project was funded by the Defence Science and Technology Organisation (DSTO) on composite propellant combustion. It has led to greatly improved understanding of the near-surface flame structure.

The science of combustion was Bob's main area of interest to which he directed the main focus of his intellect.[6] His contributions in the field made Australia a significant contributor to rigorous research in combustion, a position that it continues to enjoy. In the 1970s, he tackled the important issue of mixing in turbulent jet diffusion flames, and it was during this period that he extended the conserved-scalar theory in which analytical relationships are obtained for the flame structure as a function of mixture fraction, an ingenious concept that is commonly used today and remains closely associated with Bob's name. He developed an expression for the mixture fraction that preserves stoichiometry regardless of differential diffusion effects, and this is extensively referred to in the literature as the 'Bilger mixture fraction'.

We can see from his own words how Bob's thinking on the issue of turbulent combustion problems evolved. In the *Short History of the School of Aerospace, Mechanical and Mechatronic Engineering* Bob wrote (of himself):

> In the USA, Bilger had become challenged by the problems of predicting mixing and reaction rates in combustion systems of a non-premixed nature such as those of a fuel jet mixing and burning in air, the model problem for combustion in diesel engines, furnaces and fires. It was well known that reaction rates could not be predicted using calculations of mean temperature and composition because the correlations among fluctuating terms were hugely important. Hottel at MIT had shown that the length and other main aspects of a jet flame were determined by the rate of mixing—the 'fast-chemistry' model—when it's mixed it's burnt! But what were the effects of heat release and the consequent drastic lowering of density on turbulent mixing rates? How about predicting the effects on soot formation, so important in the radiation from the flame? Soot formation rates were slow compared with mixing rates. Soot emission from flames was a serious pollution problem for diesel engines and many other industrial combustion systems. Carbon monoxide and nitric oxide emissions were also rising pollutant problems that were controlled by chemical reaction rates that were comparable with turbulent mixing rates.

In the 1980s, Bob set himself the new objective of studying turbulence-chemistry interactions in flames.[8] He developed ingenious designs for three burners to study these effects: the piloted burner (Fig. 7), the bluff-body burner and the accelerated flow burner. During this period, he had significant influence over the development of cutting-edge laser diagnostic laboratories at the Sandia Corporation Combustion Research Facility in Livermore, California where two of the burners, the piloted and bluff-body burners, were employed to generate world-class data and a novel understanding

Figure 7. Piloted burner.

of turbulence-chemistry interaction in flames. These breakthroughs were recognized by awarding him (together with A. R. Masri) the Silver Medal of the Combustion Institute for 'an outstanding paper' presented at the Twenty-First International Combustion Symposium in Munich, 1988.

Bob's vision, devotion and leadership were critical factors in the conception and success of the International Workshops on Measurements and Computations in Turbulent Non-Premixed Flames (TNF), now in its twentieth year, which became a model for bringing experimental and numerical scientists together to tackle a particular problem. The ingenious piloted and bluff-body burners, developed by Bilger, continue to form an international platform for modellers worldwide. The challenge there is to develop reliable combustion models that account adequately for turbulence-chemistry interactions. Such models will then form the backbone of predictive numerical tools that may be used by engineers to optimize combustor designs.

This began Bob's approach to the closure problem in turbulent combustion. The problem of 'closure' in the mathematical modelling of turbulent flows has a history of more than a century. Models are needed for practical use by designers so they can confidently predict what will occur. A turbulent flame has many eddies with different length scales, all of which interact with one another as well as with the chemical time scales. Usually average quantities are of most interest, and the large-scale features of the flow are the most important. However, the small-scale fluctuations cannot be ignored. Moreover, chemical reaction occurs at the smaller scales and, in addition to the problem of turbulence, this poses two very difficult challenges: such small scales are very difficult requiring mesh sizes that render computations impractical, and the other challenge is that chemical time scales span many decades, which are again very difficult to resolve all at once hence rendering the problem 'stiff'.

The closure problem in turbulent combustion is tackled in different ways all of which are somewhat sub-optimal. Bob's ingenious approach to the closure of the chemical source term was developed in the early 1990s and was referred to as Conditional Moment Closure (CMC). This was inspired by space- and time-resolved measurements performed in the 1980s by Dibble and Masri at Sandia's Combustion Research Facility in turbulent piloted flames close to extinction. These measurements show that, when sufficiently far from blow-off, most of the fluctuations in temperature, composition and reaction rates were closely related, non-linearly, to the mixture fraction in non-premixed systems. This led Bilger to develop equations for species mass fractions and enthalpy, conditionally averaged on the mixture fraction, which could then be closed by neglecting contributions from correlations among the fluctuations about these conditional averages. A forcing term associated with the scalar dissipation of the mixture fraction fluctuations linked this work to the earlier ideas relating reaction rates to scalar dissipation in fast-chemistry flames.

Almost identical work was produced at the same time by Alexander Klimenko in Moscow. Bob became aware of Klimenko's work[9] (which does not contain experimental material) when he submitted his paper[10] to *Physics of Fluids* for publication. He then invited Alex to visit him in Sydney as a Postdoctoral Fellow where they subsequently worked together to produce

an extremely well cited paper (~393 citations in ISI Web of Science up to 21 March 2016).[11] Klimenko later was offered a position at the University of Queensland where he became a Professor.

The CMC has become a well-established, effective numerical tool for computing a wide range of reacting flows. It is used by many researchers worldwide and has become the subject of an international workshop series. For this work, Bob was also awarded in 1992 the Ya. B. Zel'dovich Gold Medal of The Combustion Institute 'for outstanding contributions to the theory of combustion'.

In the later years of his career, Bob's interests shifted to premixed and partially premixed flames as well as to the combustion of sprays. He developed novel experiments for the exploration of premixed turbulent flames in regimes in which the turbulence substantially affects the instantaneous flame structure. His work on sprays led to a novel formulation for the mixture fraction that accounts for the interaction between evaporation and turbulence near the droplet interface. This approach is now adopted by various modelling methods, such as CMC and Multiple Mapping Conditioning (MMC), to extend their application to turbulent spray flames.

Bob has served on the editorial boards of many prestigious journals in combustion. He was invited to deliver numerous plenary lectures and was awarded a suite of honours and accolades (in addition to the Silver and Gold medals of the Combustion Institute), including: a Plenary Lecture at the Twenty-Second Combustion Symposium (1988), one of five Fiftieth Anniversary Lectures at the Thirtieth Combustion Symposium (2004), Fellow of the Australian Academy of Technological Sciences and Engineering (1987), Fellow of the Australian Academy of Science (2003) and the Centenary Medal of the Commonwealth of Australia (2003).

Bob's efforts have raised Australia to the world stage as a major contributor to combustion research. He has played a pivotal role in initiating the Asia Pacific Conference Series on Combustion (ASPACC), which has brought together many combustion scientists in the region. He also chaired the Australia and New Zealand Section of the Combustion Institute, 1980–92 and was a member of the Board of Directors of the Combustion Institute, 1982–2000. Bob served as Vice-President (International) from 1994 to 1998, and during that time, he lobbied to internationalize the Combustion Institute. Then-President Bob Sawyer, wrote: 'I was able to act upon Bob's vision of the Institute as a truly international organization…His persistence eventually accelerated the process, and I believe that he was pleased at the eventual outcome'.[12]

Bob's first attendance at a Combustion Symposium was in Poitiers in 1968. He often told the story of how, during the train ride from Paris to Poitiers, he shared bread with colleagues attending the same meeting, and this led to life-long friendships. He was always accompanied by his beloved wife Jill. His presence was always felt at these meetings through the pointed questions that he asked and the profound issues that he raised.

Bob was instrumental in bringing the Twenty-Fourth International Combustion Symposium to the University of Sydney in 1992. This was a first-time event for Australia and perhaps remains one of Bob's proudest moments. Coincidentally, at the opening day of the Symposium, there was a spectacular fire in a nearby wool store. Many delegates watched in awe, and this set the scene for a very successful conference.

With his unique personality, Bob has impacted the lives of so many, who were as stunned as we were by his passing. Scores of emails were sent by colleagues around the world reflecting on how Bob had touched their lives. Professor Bob Dibble from UC Berkeley refers to him as the 'Lion of Oz,' while Professor Nondas Mastorakos from Cambridge reflects on Bob as follows: 'I cannot express how much I owe him on a professional level. But equally important was the fact that he treated me as a friend, and I am forever grateful for that. His love for combustion was probably matched by his love for cooking, and we had many wonderful evenings together talking about both'.

Closure

There are many who deserve thanks for their help with this study. We thank the Bilger family for finding documents and photographs from Bob's well-kept files and for sharing personal memories. We are also grateful to many colleagues around the world, particularly Dr Rob Barlow

and Professors John Kent and Bob Dibble who provided comments and reflections on Bob as a friend, mentor, great scientist, but more importantly, as an amazing human being. The Australia and New Zealand Section of the Combustion Institute is eternally grateful for Bob's service and proud to commemorate him by naming the Opening Lecture of its biennial conferences as The Bilger Lecture.

We continue to celebrate his distinguished academic career at the University of Sydney. He leaves behind a cohort of former students who have had excellent careers in Australia and worldwide. Aside from his work in teaching and administration, he devoted time to the successful start-up of the Warren Centre for Advanced Engineering and to the Mechanical Engineering Student Association (USMEA). His applied and basic research work have been very fruitful and the basic work on combustion is universally recognized; his most important contribution is the pioneering of the use of conditional moment closure methods in the subject, and he also made significant contributions to environmental and combustion chemistry.

Bibliography

A full bibliography of scientific publications by Robert William Bilger is available online as Supplementary Material to this paper.

Endnotes

1. R. W. Bilger, 'Research Consulting in the United States', *Engineering Year Book* (1965), 89–91.
2. L. M. Trefethen, R. W. Bilger, P. T. Fink, R. E. Luxton and R. I. Tanner.'The Bathtub Vortex in the Southern Hemisphere', *Nature*, 207 (1966), 1084–1085.
3. *The Warren Centre News*, vol.1 (1982) No. 1, p. 1.
4. R. W. Bilger, *Japan Journal* 3 May–13 June 1985.
5. M. J. Atkinson and R. W. Bilger, 'Effects of Water Velocity on Phosphate-uptake in Coral Reef-flat Communities', *Limnology and Oceanography*, 37 (1992), 273–279.
6. A. R. Masri and S. B. Pope, In Memorium Professor Robert William Bilger, 1935–2015', *Combustion and Flame* (in press).
7. Bob Bilger, 'Thermo Fluids', Chapter 3 in V. Kirkpatrick (ed.), *A Short History of the School of Aerospace, Mechanical and Mechatronic Engineering*, The University of Sydney, *http://web.aeromech.usyd.edu.au/history-chapters/C3%20ThermoFluids.pdf* accessed July 2016.
8. A. R. Masri and R. W. Bilger, 'Turbulent Nonpremixed Flames of Hydrocarbon Fuels Near Extinction: Mean Structure from Probe Measurements', *Proceedings of the Combustion Institute* 21 (1988), 1511–1520.
9. A. Y. Klimenko, 'Multicomponent Diffusion of Various Admixtures in Turbulent Flow', *Fluid Dynamics*, 25 (1990), 327–337. (This is a translation; the paper was published in Russian in 1989).
10. R. W. Bilger, Conditional Moment Closure for Turbulent Reacting Flow', *Physics of. Fluids A*, 5 (1993), 436–444.
11. A. Y. Klimenko and R. W. Bilger, 'Conditional Moment Closure for Turbulent Combustion', *Progress in Energy and Combustion Science*, 25 (1999), 595–687.
12. Masri and Pope, already cited (n. 6).