Daniel D. Joseph

1929–2011

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

DANIEL D. **JOSEPH**

March 26, 1929–May 24, 2011

Elected to the NAS, 1991

Photography by Charles Joseph

By Katepalli R. Sreenivasan

Sometime in the early eighties, I found myself in a hotel limo with two others, one of whom was Bill Reynolds from Stanford. The description to Bill of my work on combustion instability seemed to please him, more likely its enthusiasm than the content, and he turned to the other person, unknown to me in person until then, and said, "Dan, did you hear that?" That was my introduction to Dan Joseph, whose work I had known and admired for some years already. Since that time, I had opportunities to witness how Dan inspired numerous creative ideas, won the adoration of his students and junior colleagues, and earned a high level of professional respect and a number of peer recognitions.

Dan was an active communist in his youth, and his first two degrees were in qualitative sociology. Thus, there are two plausible strands to Dan's life story. One of them, a compelling one at that, is the transformation of this ardent communist to one with a free-market outlook later in life, concerned about stock markets and Wall Street. Perhaps he was simply an exemplar of the dictum, attributed to famous names such as Benjamin Disraeli and Winston Churchill (and many French Statesmen) that anyone who is not a liberal at 20 years of age has no heart, while anyone who is still a liberal at 40 has no head; but the circumstances are also specific to Dan and I will follow this strand indirectly and incompletely in section 2, which provides a skeleton of Dan's biography. The second strand, the academic one, which is public in a broad sense, is this: with initial degrees in sociology, how did Dan become a world-famous fluid dynamicist with highly proficient mathematical skills? I will dwell on this aspect in somewhat greater detail than the first, focusing on Dan's principal scientific contributions; this is done in section 3 but with some minor details interspersed in section 2. This essay will end with a brief assessment of Dan's legacy in section 4.

Biographical Sketch

Daniel Joseph was born on March 26, 1929 in Chicago and had but one sister who died young. His father, Samuel Joseph, was a Jewish migrant from Odessa, and arrived in the US sometime during the late 19th or early 20th century. His mother, Mary Joseph, born in the US, was from a Jewish family of Polish origin. They were Conservative Jews and did not follow their religion particularly rigorously. Samuel Joseph was a middle class owner of a jewelry shop in downtown Chicago, where Dan occasionally worked in his youth. In spite of his Russian-Jewish background, Dan didn't learn to speak Russian or Yiddish; for instance, his means of communication with his paternal grandmother, who stayed with his parents, was apparently mostly through smiles. Dan went to John Marshall Metropolitan High School, a public school on the West side of Chicago; he himself described his academic performance as average; basketball and weightlifting seem to have been his main distractions from school work. Growing up during Depression Days had its imprint on Dan's outlook.

The religious aspects of Judaism did not particularly appeal to him. One reason may well have been that the rabbi who performed Dan's Bar Mitzvah belittled both him and his father, on that occasion, for not being sufficiently involved in the synagogue. Dan simply stood apart from ceremonial aspects of Judaism though he stayed close to its ethnic aspects. He was initially taken aback, at least for a short time, when his children returned to the religious fold quite strongly, but he reconciled with it soon enough.

Dan married Ellen Broida when he was about 20 years old. Ellen's father, Samuel Broida, migrated about the same time as Dan's parents from around Vilna (Vilnius), but her mother, Ida, was born in the US. They were Orthodox Jews, and Samuel Broida became a rabbi with some success and standing. Dan was still working for an undergraduate degree in Sociology at the University of Chicago, and his father-in-law put him through the rest of it. He went on to do graduate work, also in Sociology, and received a terminal Master's Degree in 1950.

In the meantime, Dan and Ellen reinforced each other in their communist leanings (which may have been fortified during their time as a young couple in France). By design, they were not registered party members so they could remain free and arrange to hide party leaders in case warrants were issued for their arrest. This political activity was especially intense when Dan and Ellen stayed in Berkeley, the hotbed of student activism those days, for a year or two after Dan's Chicago education (while their first offspring, a daughter, was already born). The FBI had separate files on the couple, and interviewed them individually at some point during the McCarthy era. The couple had the idealism to help the desegregation of their neighborhood whenever an African American family moved in, by making friends with them and lending them moral and material support as friendly neighbors.

During his stay in Berkeley, as part of the proletariat sense of belonging, Dan worked as a machinist in a factory, and picked up modest analytical skills in the process. It is not known whence came the inspiration to pursue engineering but, at the end of that period, he thought that a technical degree would gain him more respect, returned to Chicago and enrolled in Illinois Institute of Technology (IIT) for a Mechanical Engineering degree. IIT was the obvious choice because both Dan and Ellen wanted to stay close to their families. By 1956, they had both left the Communist party, having been disillusioned by stories of atrocities that had begun to emerge in the West about the Stalin era, and by Soviet adventurism in Eastern Europe.

The evolution from a sociologist to a mechanical engineer was fraught with great anxiety. In fact, Dan is known to have literally cried in front of Ellen for being unable to understand, despite hard work, the mathematics that was required of him in a rigorous engineering program. But he persisted with admirable tenacity, a trait that stayed with him until the last. The subjects simply yielded to his rectitude and determined effort, and he got his BS (1959), MS (1960) and Ph.D. (1963), all from IIT. His thesis advisor was L.N. Tao, a moderately active but traditional researcher. Dan obviously made a good impression on his mentors and was recruited as an assistant professor even before he had formally received his Ph.D. He moved to the University of Minnesota only a year later. He was rapidly promoted to full professor in about 5 years, elevated to the Russel J. Penrose Professor in 1991 and to the Regents Professor in 1994 (this being the highest academic distinction within the University). In addition, he was a Distinguished Adjunct Professor at UC Irvine, Honorary Professor at Xi'an Jiao Tong University in China, and a visiting professor at various times at the universities of Sussex, Melbourne, Nice, Naples, Rome, Paris, and Orsay, as well as the Weizmann Institute and the Institut des Hautes Etudes in Bures-sur-Yvette. His matter-of-factness about the academic job ("it seemed like a good job, the pay was good enough, the prestige was good enough and I liked ideas and I liked to study") belies the enjoyment he derived and success he attained as an academic. Though formally retired in 2009, he took no break from his research.

After moving to Minneapolis, Dan chose to live away from Jewish neighborhoods of the sort in which he and his wife had grown up and, after a short time, bought a house with a porch overlooking the lake in Shoreview. The house had a machine shop in the basement, where Dan sometimes made utilitarian furniture and a blabber boat that the family enjoyed on the lake. He and Ellen shared this home, with their children—Karen, Michael and Charles—when they were growing up, for some twenty years. Dan and his second wife, Kathleen Jaglo, to whom he was married in 1990, chose to live in an apartment in Riverview. His family members are unanimous that Dan's first love was his work and his students, as Kathleen and Charles have remarked (with admiration, I must note). Dan felt proud that he did not fuss over his children as they were growing up, but became quite worried in later life that he might not have given them enough attention (and compensated for it in various ways).

Dan had opportunities to move from the University of Minnesota to better-known institutions but chose to remain there throughout his career (with occasional and extended visits to other places); more than once he expressed happiness with his department, though there were some tense periods. There, he taught generations of students, wrote more than 400 papers in a continual stream, authored or co-authored seven books, edited six more, consulted widely, took out some ten patents, and supervised some 50 Ph.D. students (some 40% of whom are professors in universities around the world). He was able to accomplish all this, and more, through unstinted passion for his work and the ability to inspire and extract the best out of his students; and he always seemed to know the sorts of problems that would yield to his effort, and didn't waste time agonizing over others.

Dan's perennial interests outside his scholarly work were his jogging, music (classical and rock—The Rolling Stones, in particular), and opera. It was well known that he was an avid jogger—in winters he would jog along the campus corridors even before the cleaning crew showed up—and would train for marathons (some 22 of them), running once in Greece along the route of the historically first marathon. This was a matter of great satisfaction for him (though he was not a fast jogger and would occasionally tire himself out), and he carefully preserved all the medals that marked his participation.

Dan was somewhat of a contrarian in his life, never embarrassed by shifts in his own thoughts and philosophy. He would listen to music not only while jogging and working in the laboratory, and is reputed once to have lectured even as the earbuds streamed music in his ears. (It is not known how his students reacted to it.) He would occasionally lecture in his shorts, just back from jogging. The many cups of coffee he consumed during the day would keep him somewhat high strung, so he took every minute outside of his work environment (e.g., while playing with his grandchildren) to be somewhat of an acquiescing participant. Increasingly, however, he allowed societal norms to penetrate his life.

Dan Joseph passed away on May 24, 2011 at the age of 82 of cardiac arrest at the University of Minnesota Medical Center in Minneapolis. His family, students and many of his friends felt a great loss.

Scientific Work

We now shift attention to the scientific strand of Dan's life. His interest in fluid dynamics was "a historical accident" (as he sometimes said), but the passion he developed subsequently was deep and real. He began with a study of fluid flows in geometries with permeable bounding surfaces and ended it with considerable interest in small particles that disperse violently upon contact with a liquid surface (and the boldness he showed in his later research does not seem to have originated with his thesis advisor). Dan himself has said: "My career can…be understood in two phases, the first emphasizing mathematics and the second, engineering." This is a plausible basis for summarizing his work. Equally relevant is that, even though he was the author or coauthor of many scientific papers, several of them highly original and laden with excellent physical understanding, he often thought that research papers were a prelude for writing books. Each of the books he authored and edited represents a different facet of research that interested Dan at different points of his career, and indicates what he regarded as important. I will dwell on a few central themes.

Even some ten years after his transformation from sociology, its taste lingered on. He would occasionally compare instability of fluid flows with social upheavals such as revolutions. In the Preface to his first set of books on stability of fluid flows (more about them later), he said:

> *I started writing this book in 1967 at the invitation of Clifford Truesdell [but] the theory of stability has developed so rapidly since 1967 that the book I might then have written would now have a much too limited scope. I am grateful to Truesdell … for the generous way he has supported my efforts and encouraged me to higher standards of good work. I have tried to follow Truesdell's advice to write this work in a clear and uncomplicated style. This is not easy advice for a former sociologist to follow; if I have failed it is not due to a lack of urging by him or trying by me.*

Parenthetically, as Dan's work turned increasingly physical and empirical, Truesdell got disenchanted with his work and made it known. The two of them moved apart with palpable discontent on the part of both.

The Mathematical Phase

For this "first phase" of his work, Dan focused on the rich topic of stability of fluid motion, as mentioned above. That fluid flows occur in laminar and turbulent states is a matter of common experience: smooth and regular under some conditions, and rough and irregular under others. The understanding of the transition between the two states is a major objective of fluid dynamics research, and the loss of stability of flows has played a pioneering role in this effort. It is well known that the so-called Reynolds number, R, often marks the state of stability. There are many questions that one can ask, but one class of questions can be summarized as follows: Is there a sufficient condition of stability, marked by the value R_E of the Reynolds number R, such that a flow is unconditionally stable for all $R < R_E$? The computation of R_E is the main goal of the energy theory. This is the theory to which Dan turned his attention. The first attempt of this sort was made by W.M.F. Orr in 1907 but the modern approach pioneered by James Serrin in 1959 laid the foundation for Dan's work. Serrin (much admired by Truesdell) was Dan's colleague at the University of Minnesota, but it is not clear if he influenced Dan directly.

Dan's work in this area led to two highly regarded monographs, *Stability of fluid motions, I and II.* Dan was well aware that Landau and Hopf's scenario, that turbulence is the result of repeated bifurcations, was essentially wrong but it was also clear to him that some basic notion of branching of solutions should play an important role in understanding how flows evolve towards a turbulent state. He believed that much insight could be gained through precise understanding of specific problems, which is how he set up his books.

The segregation into two volumes is somewhat artificial and we may discuss them as one without any loss. Among other topics, these volumes present original work on the global stability and uniqueness of flow through annular ducts, Couette flow between rotating cylinders, spiral Couette-Poiseuille flows, and the flow between concentric rotating spheres; they also discussed the global stability of a motionless heterogeneous fluid with constant gradients of temperature and concentration, the variational theory of turbulence applied to convection in porous materials heated from below, stability problems for viscoelastic fluids, and problems of interfacial stability. I found myself drawn to them greatly soon after the books were written: they provided a careful account of the state of the art at the time, and exuded the sense that rapid progress was being made on the topic of stability (when linear and nonlinear theories were taken together). This did not mean that the work contained no quirks (e.g., the claim that the pipe flow is the limit of an axial flow in an annulus as the inner diameter shrinks to zero), but they were minor enough that they did not mar the sense of accomplishment that the books conveyed.

There is no better way to demonstrate the esteem in which these books were held than quote from a review written by Keith Stewartson, an eminent applied mathematician in his own right (JFM 88, 204-208, 1978):

> *Now, after several years preparation, one of the most distinguished mathematicians working in this area has written a book setting out the modern position in many aspects of this challenging and difficult subject. He is obviously at home with most of the principal ideas in current use—bifurcation theory, variational principles, perturbation techniques, continuous materials—having played an important role in shaping them, and with the experimental evidence on the behavior of fluids. The result is a book of remarkable insight, breadth and creativity which students of stability will consult and treasure for many years to come.*

Stewartson expressed a few reservations as he proceeded in the review, one of which was that “it was just not possible to give an equally broad perspective to all topics added”, but he immediately ameliorated this reservation by adding, “especially as the author was simultaneously making new contributions at a phenomenal rate”. He reiterated his admiration for the books with the concluding paragraph:

> *… I am confident that the book is essential reading for established workers in stability, who had better keep in close touch with Joseph’s work if they wish to be abreast of future developments. Beginners will benefit greatly from it, especially after having had some grounding in linearized theory. A particularly valuable and unusual service is provided for them by the author in giving a large number of examples, ranging from the easy to the difficult, which are interspersed throughout the text to enable the student to develop facility in the wide variety of ideas advocated. For all interested in the stability of fluid motions the book will be a source of pleasure and stimulation.*

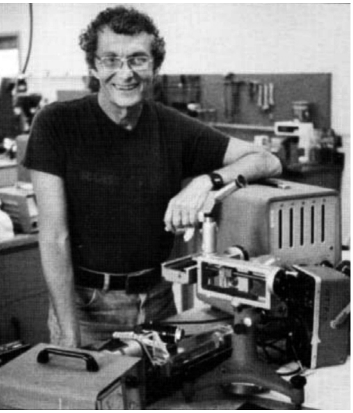
A ringing endorsement!

The next step was the undergraduate textbook with Gérard Iooss on *Elementary Stability and Bifurcation Theory*. The book was begun in 1978 when Iooss visited the University of Minnesota and was published in its first edition in 1980. For Dan, it was a natural outgrowth of his stability work (in which he was already using the language of bifurcations more than is the standard in such instances), and he was learning with excitement new mathematical tools even as he was writing about them. The book was timed well because the interest in the subject was expanding, but the risk was that many new developments that were occurring roughly simultaneously could not be included. It was meant for a wide audience of "engineers, biologists, chemists, physicists, mathematicians, economists and others whose work involves understanding equilibrium solutions of nonlinear ordinary differential equations." This intended generality and the simplicity the authors also sought in a primarily undergraduate textbook (with many appendices and exercises) meant that various compromises were made. For instance, while one finds in the book Edward Lorenz and David Ruelle as well as quasiperiodic solutions, one does not find either Mitchell Feigenbaum or the associated period doubling work; it covered only local bifurcation theory and not the global bifurcation analyses; nor did it include the important effects of symmetry on the bifurcation properties; and it did not make any effort to systematically refer to the literature. Although the second edition, prepared some ten years later, revised the content, the spirit and essence remained essentially the same. Though the book formed the basis for a successful advanced undergraduate course, it appears to have been overtaken soon by other books on similar topics.

The "Engineering" Phase

Even though Dan himself felt that there was some discontinuity of emphasis between the "first" and the "second" phases of his work, I expect that history will record them as a continuum. In fact, the flow configurations he considered in the "second phase" were often not different from those of the "first phase". There was no doubt, however, that Dan was turning attention increasingly to experiments (and named his lab "The Lab of Lucky Breaks") and to a style and tradition that combines them with analysis to extract the essential physical understanding. I select three areas in this sub-section and conclude with a fourth in the following sub-section.

Viscoelastic liquids: After a decade of immersion on these mathematical problems, with almost no temporal gap, Dan directed attention to the rheology of viscoelastic fluids, with focus on slow-moving flows. The work did not distance itself from mathematical formulations (nor was it a new subject for Dan, as we have already seen from the contents of his books on stability) but made undoubtedly closer contact with experiment



Dan at work in his lab.
(Photo provided by Howard Hu.)

and data. His book, *Fluid Dynamics of Viscoelastic Liquids*, develops a tour de force mathematical and physical theory, as well as insightful experiments, that resulted primarily from the research of his group. The book is not easy to digest but it opened up this vast area to analytical treatment as had not been done before. He used mathematics wherever possible but didn't hesitate to provide folksy descriptions where mathematical treatment was not possible. A significant discovery was that the unsteady vorticity equation for many models of viscoelastic fluids is hyperbolic, giving rise to waves of vorticity. In steady flows, the vorticity field can be hyperbolic in one place and elliptic in another, as in transonic flows of air. The key quantity in the discussion of hyperbolic waves of vorticity is the speed of shear waves. Dan and his students studied several problems such as anomalous heat and mass transfer across small wires, drag reduction, die swells, and inertial tilting of cylinders settling in viscoelastic liquids. In all these phenomena, a viscoelastic Mach number appears as the important rheological parameter. Spurred by theory, Dan also invented a device in 1986 for measuring the speed of these waves, and followed it up by measurements in a large number of fluids and flows.

Two phase fluids: Dan's next set of investigations concerned two-phase fluids, presented in two volumes of *Fundamentals of Two-Fluid Dynamics*, authored with Yuriko Renardy. Many of the most interesting problems in two-fluid dynamics are tied to the preferential positioning and shaping of the interface, so that interfacial stability is a major player. When Dan started his studies in the early 1980's, it was not evident that stability theories would actually work in the complex environment of two-phase flows. Dan and his collaborators devised a number of elegant experiments to explore physical phenomena, studied their stability, and proposed simple explanations for their observations; and they seem to have been somewhat surprised by the success of stability theory in explaining their observations. In any case, the principal topics covered in the books are two-fluid flows in a rotating cylinder, the Bénard system of two-fluid layer, planar channel flow of channels under gravity, etc. Particular mention must be made of the work on water-lubricated transport of heavy viscous crude oil; this work was particularly significant to Dan. The oil travels within a sheath of water along the pipeline, thus reducing the drag and the pumping power, a phenomenon that Dan explained in anthropomorphic terms:

"High viscosity liquids are lazy. Low viscosity liquids are the victims of the laziness of high viscosity liquids because they are easy to push around." This loosely-stated principle, while not being universally true, helped explain some complex behaviors.

Fluid-particle interaction: In the late 1980s and early 1990s, Dan got interested in the problem of interactions between fluids and particles at finite particle Reynolds numbers. At that time, there was considerable literature on particulate suspensions, and analytic as well as computational techniques for fluid-particle motion had been developed for low Reynolds numbers. However, there were many applications beyond the limit of low Reynolds numbers, and Dan understood the need for new computational methods for making progress. He dedicated the next decade to this problem, to which he referred, somewhat anomalously, as "direct numerical simulation of solid-liquid motion". He formed an interdisciplinary multi-university team of engineers, computer scientists, and applied mathematicians to lead a massive effort to develop computational methods for fluid-particle motion. The primary source of support was a "Grand Challenge Project" funded by the National Science Foundation.

There were two immediate scientific challenges to overcome. The first was to couple fluid-particle motion so that numerical schemes were stable, and the second was to efficiently handle the continuously changing fluid domain. Dan and his students overcame these challenges and extended them to simulations even in viscoelastic fluids. Application of these tools led to papers on the fundamental understanding of single particle motion in channels, the origin of lift force on particles, two-body interactions (drafting-kissing-tumbling in Newtonian fluids or drafting-kissing-chaining in viscoelastic fluids), and many-particle systems, all at finite Reynolds numbers. Dan and co-workers introduced several new modeling ideas for lift force on a single particle and its generalization to particles in concentrated suspensions, which he called "fluidization by lift."

The development of new computational capabilities required the establishment of new test cases. The "drafting-kissing-tumbling" scenario, describing a rearrangement mechanism in which a sphere interacts with the wake of the preceding one in a particular way, has now become the standard test case in validating computer simulation of particulate flows. In subsequent decades, these efforts advanced to simulations of moving elastic bodies in fluids, swimming and flying organisms, underwater and aerial robotic vehicles, and fluctuating hydrodynamics-based Brownian systems.

Dan was proud of his decade or so of commitment to computational approaches even as he continued exploiting his analytical and experimental skills. Heading this multidisciplinary effort seems to have been the only leadership role he took on outside his own research group. His 2002 web-based book *Interrogations of Direct Numerical Simulation of Solid-Liquid Flows* describes the major aspects of his contributions in this area.

The Last Decade

In the last decade of his life, Dan worked primarily on viscous irrotational flows, and regarded this work as best suited to his taste—fundamental yet specific. The results obtained by his group, dispersed in a number of scientific articles, were put together, with Toshio Funada and Jing Wang, in the book *Potential Flows of Viscous and Viscoelastic Fluids*.

In this book and in papers preceding it, Dan held the view that, when considering irrotational solutions of the Navier-Stokes equations, it is never necessary, and typically not useful, to put the viscosity to zero; and that standard phrases like "inviscid potential flow" or "viscous potential flow" confuse properties of the flow (potential or irrotational) with properties of the material (inviscid or viscous); that it is better and more accurate to speak of the irrotational flow of an inviscid or viscous fluid. The main point is this: Potential flows $u = \nabla \varphi$ are solutions of the Navier–Stokes equations for viscous incompressible fluids for which the vorticity is identically zero. The viscous term $\mu \nabla^2 u = \mu \nabla \nabla^2 \varphi$ vanishes, but the viscous contribution to the stress in an incompressible fluid does not, in general, vanish. While no-slip cannot be enforced in irrotational flows, eliminating all the irrotational effects of viscosity by putting $\mu = 0$ to satisfy the no-slip condition is "like throwing out the baby with the bath water." To Dan's disappointment, much of the community did not share the same level of enthusiasm for this work. (I should know because I was the editor or the adjudicating referee for a few of his papers on the subject.)

The reason for skepticism goes roughly along the following lines. Ludwig Prandtl showed us how to approximately solve the complex nonlinear problem of flow past a slender obstacle: divide the flow into two non-overlapping domains, one of which is a thin boundary layer in which viscous and inertial forces are of the same order and the other in which viscous forces are negligible, and solve the flow in the two regions separately with properly valid boundary conditions, and merge the two solutions. The general idea since then has been, as much in fluid mechanics as in other areas dominated by nonlinearities, to organize the solution domain on the basis of dominant force balances and proceed along the lines pioneered by Prandtl. The case made by Dan and co-authors has been that viscous potential flows provide another organizing paradigm in fluid dynamics. But does it give first-order insights that could not be had otherwise? This is the question in the minds of his skeptical colleagues and one that Dan and his coauthors tried to address via a large number of examples in the book, encompassing topics such as rising bubbles, Rayleigh-Taylor instability, Kelvin-Helmholtz instability, Faraday waves, jets, cavitation, viscoelastic fluids and their stability. My provisional impression is that the last word on this topic hasn't yet been said, for which a more diligent look at the book's content will be needed.

Other Intellectual Pursuits

In the midst of this extraordinary busy research life, Dan somehow found time for other activities as well. Abiding scholarship in his case was combined with interest on practical matters, as well. To illustrate:

- He was listed as associate editor of the following scientific journals: *Archive for Rational Mechanics and Analysis*, *Journal of Applied Mechanics, SIAM Journal of Applied Mathematics, Journal for Society for Interaction of Mathematics* and *Mechanics, Journal of Non-Newtonian Fluid Mechanics*, Theoretical and Computational Fluid Mechanics, *International Video Journal of Engineering Research*, *European Journal of Mechanics B/Fluids*, *International Journal on Bifurcation and Chaos in Applied Sciences & Engineering*, *International Journal of Multiphase Flow, Pan American Mathematical Journal, Springer Series on Interdisciplinary Applied Mathematics,* and *Journal of Differential Equations and Nonlinear Mechanics*. Their diversity provides some evidence for Dan's breadth of interests.

- He consulted for a number of companies on a variety of problems involving multiphase and viscoelastic flows; examples include Pillsbury, Shell, Gillette, Proctor & Gamble, M&M Mars, and Schlumberger-Doll.

- He held ten US patents on practical problems, resulting from laboratory research: Patent Number 4,602,502 on the wave-speed meter; 4,644,782 on spinning rod interfacial tensiometer; 5,150,607 on spinning drop tensiometer; 5,301,541 on determining drag on surfaces; 5,385,175 on oil transportation; 5,646,352 for measuring aspects of multiphase flows; 5,922,190 to suppress foam formation in a column of bubbles; 5,922,191 for foam control using fluidized bed of particles; 5,987,969 for determining dynamic stability of emulsions; and 5,988,198 for pumping bitumen froth through a pipe line.

Dan Joseph's Legacy

The legacy of an academic is measured through the durability of their research and the mentoring of his or her students; opportunities to build and foster the growth and reputation of institutions fall to the lot of very few. In a large university such as Dan's, keeping track of one's impact on undergraduates is hard and done only sporadically (and Dan was not especially focused on undergraduate teaching), and so one looks instead to Ph.D. students and post-docs whose careers were shaped by the work they did with their mentor and the scientific attitudes they developed during that association. I have sketched Dan's research, some of it his own and some done jointly with his students, and it seems clear that there is much in that work that will be revisited in due course. He will be remembered more for being the first person to "get there", rather than for being the person who said the last word; the harder part in Science is asking the right question (to paraphrase Gertrude Stein)—and Dan was at his best in that art. He attributed his success, partly in jest, to his fondness for "low hanging fruit", but the statement belies his astuteness in selecting problems that required first-order understanding. Altogether, it is fair to say that he was a giant in his field.

What brought him true pride were the 50 Ph.D. students whom he supervised ("I owe so much to the string of superb students who have worked with me"), and who, in turn, remain greatly devoted and loyal to him. I already mentioned that some 40% of them are university professors; most others are employed in industry. Never the one to rest on past laurels, Dan was incessantly pushing himself and others around him to think about new problems. What earned Dan his students' love was that he was always encouraging of their efforts, never belittling their output; the fact that he himself frequently changed his fields of research kept him constantly aware of the tenuousness of creative life. In the Preface to the book on potential flows, cited earlier, one finds the statement: "We worked day and night on this research; Funada in his day and our night and Joseph and Wang in their day and his night. The whole effort was a great pleasure." This work ethic describes part of Dan to the end. He kept himself young in this way—and, for this reason, in the minds of many who knew and admired him, Dan will never die.

Three accurate characterizations of Dan were astuteness, creativity and hard work. He did not succumb to expensive equipment; nor, most of the time, to heavy computations. Though he said, more than once, that one "should take care of [one's] reputation," he never let a potential controversy, such as negative reports that he sometimes received from the referees of his articles, interfere with his creativity. Despite his commitment to research, he did not spend his typical day always on research and teaching. His jogging took some time, and it was part of his philosophy that one must take care of one's body. He consulted for both local and international companies and wanted to make a difference in the real word. He began to closely follow the rise and fall of the stock market ("you must take good care of your money" was his refrain) for all the time I had known him. He did a fair amount of politicking on behalf of his students and colleagues, as well.

In recognition of his impact, Dan was honored by several important awards including membership of the US National Academy of Sciences and the US National Academy of Engineering, Fellowship of the American Academy of Arts and Sciences, Guggenheim Fellowship, the G.I. Taylor Medal of the Society of Engineering Science, the Timoshenko Medal of the American Society of Mechanical Engineers, the Schlumberger Foundation Award, the Bingham Medal of the Society of Rheology, Fellowship and Fluid Dynamics Prize of the American Physical Society, Distinguished Service Award of the US Army, and named Lectureships in several distinguished departments; he was also listed among the highly cited researchers by Thompson Scientific. He took childlike delight in awards and recognitions, even the small ones he received long after the big ones, and sometimes stated with genuine tenderness as to why he had earned them.

Dan is survived by his wife Kathleen (Kay) Jaglo Joseph, his daughter Shifra (Karen) Chana Hendrie, and sons Charles Joseph and Samuel Guillopé Weissler, 13 grandchildren and 2 great-grandchildren; to his great sorrow, he was predeceased by his son, Michael Joseph.

ACKNOWLEDGMENTS

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Dan is on record for stating that the happiest day of his life was when he learnt the collapse of the Nazi rule in Germany.

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