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OFFICE OF THE PRESIDENT

MEMORIAL RESOLUTION
JOHN VALENTINE BREAKWELL
(1917 - 1991)

John Valentine Breakwell, Emeritus Professor of Aeronautics and Astronautics, died of cancer at his home in Palo Alto on April 16, 1991.

A brilliant applied mathematician, he made important contributions to celestial mechanics, the calculus of variations, trajectory optimization and guidance, differential games, and statistics.

Born in Switzerland of British and American parents, he attended Eton and received a degree in mathematics with first class honors at Oxford University in 1938. He was a pacifist and came to the United States in 1938 to avoid military service in Great Britain. He studied music composition and mathematics at Harvard, and, after making the difficult choice between these two creative loves of his life, he chose mathematics, receiving his Ph.D. in 1941.

He taught mathematics at Tufts University from 1941 to 1949, then worked as a research scientist for North American Aviation in Los Angeles until 1957, when he joined the Lockheed Missiles and Space Co. in Sunnyvale. He became a professor at Stanford in 1964.

While at Tufts he married Lilyan Wiley, an early English friend, who died in 1984. He is survived by their son, John Alexander Breakwell of Los Altos, California, and three grandsons. He spent much of his last few years with his devoted friend and fellow musician, Barbara Nygren.

While at North American, he wrote one of the key papers on the modern calculus of variations, "Optimization of Trajectories." His presentation was crystal clear, and his application to the numerical optimization of booster ascent trajectories for injecting satellites into orbit was remarkable. The problem he solved was finding the direction of the booster rocket thrust as a function of time so that the satellite arrived in minimum time at the desired orbital altitude with the correct orbital velocity. This paper was not published until 1959, two years after Sputnik, but the work was clearly done before Sputnik. In this paper, he gave an interpretation of the Lagrange multiplier functions (adjoint variables) as sensitivities, which connected them to the gradient of the cost function in Richard Bellman's new concept of "dynamic programming" (1957). That interpretation is the key to understanding the calculus of variations for most engineers.

He and Rufus Isaacs (independently) created the modern theory of differential games which treats minimax strategies, or how to determine optimal strategies in a competitive game. His paper on the "homicidal chauffeur" (1969) is considered a classic in the field. It describes the strategies that a driver and a pedestrian should use when the driver wishes to run down the pedestrian on a big field as quickly as possible, and the pedestrian wishes to survive as long as possible. The driver has a speed advantage but a minimum radius of turn, while the pedestrian can turn abruptly; the optimal strategies are amazingly intricate. He later applied the theory in an amusing paper about football, considering the strategies that the ball carrier should use to elude two downfield tacklers and their strategies in trying to catch him. The theory has applications to war games (much to his sorrow as a pacifist), economic competition, and feedback control where one is interested in the worst disturbance history that the controlled object might encounter (*e.g.*, wind in controlling an aircraft).

His work at Lockheed and Stanford with colleagues and students on astrodynamics, the modern version of celestial mechanics, dealt with predicting spacecraft orbits in the presence of perturbations, a complicated but important subject for space exploration. He invented "halo orbits" which are fascinating orbits about a point in space where the gravitational forces of two celestial bodies are in equilibrium with the centrifugal force. One of these was flown by NASA in a halo orbit about the sun, thanks to one of John's students, Bob Farquhar.

He was an important contributor to the NASA-Stanford Gravity Probe B project which will make a new test of Einstein's theory of general relativity using a satellite probe launched from the space shuttle in the 1990s.

John appeared unaware of the significance of the many new contributions he made. Instead he showed his admiration for the talents he perceived in his students and colleagues. He was unpretentious and shared credit for many of his insights with his students. Many of his fine technical contributions were never published in archive journals and only appeared in conference proceedings; he was too busy doing something new to revise these papers for submission to journals. It was not long before he was recognized internationally as a leader in orbital mechanics and differential games. He received the Mechanics and Control of Flight Award of the American Institute of Aeronautics and Astronautics in 1972, the Dirk Brouwer award of the American Astronautical Society in 1973, a Humbolt Fellowship from Germany in 1977, and the Control Heritage Award of the American Control Council in 1984. He was elected to the National Academy of Engineering in 1981. He was an associate editor of the Journal of Optimization Theory and Applications from its inception in 1967.

He was a remarkable teacher-consultant, since his quick mind enabled him to rapidly understand almost any problem and to suggest solutions or approaches that almost always worked. An example of his tremendous insight into dynamics and mathematics occurred when his student John Edwards was trying to calculate an example of stabilizing a simple low-speed aeroelastic system using the unsteady aerodynamic theory developed by Theodorsen and Garrick in the 1930s; their results were expressed as integrals along the imaginary axis and around the complex right half plane; this is useful for describing the open-loop unstable behavior but not very useful for describing a stabilized system with feedback. R.T. Jones had shown a simple approximation to Theordorsen's theory about 1940, but Edwards wanted to get the exact solution. Breakwell looked at this dilemma and said that he thought the integrals could be continued analytically into the left half plane; in a few hours he had done so, and, in addition, he determined the jump in the function across a branch cut along the negative real axis. Edwards then calculated, for the first time, the exact behavior of an aeroelastic system stabilized with feedback to a trailing edge flap. This was a very significant breakthrough in the understanding of how to stabilize aeroelastic systems.

He also had a remarkable memory and he loved surprises. At Lockheed in the 1960s he worked on planning the orbits of the Discoverer satellites. If you happened to be traveling with him just after sunset, he might suddenly point and say, "Look over there." A few seconds later, a brilliant star would come into view and speed across the heavens; it would be a Discoverer satellite whose ephemeris he had calculated and kept in his head.

Once, during a Messiah rehearsal, he stepped outside at a break to watch a Discoverer pass, then rejoined the rehearsal in full voice as he re-entered the auditorium.

On another occasion a mystery satellite was detected by the Air Force; apparently, the USSR, for the first time, had not told us of a satellite they had launched. John thought about a picture-taking Discoverer we had recently failed to recover, and calculated its orbit assuming it had been mis-oriented 180 degrees when the de-orbit retrorockets were fired; this orbit matched the orbit of the mystery satellite exactly, much to the relief of the State Department.

To celebrate that feat we asked John to speak, on a topic of his choice, at a new seminar series on Guidance and Control. To our surprise, he presented a new and fascinating analysis of the dynamics of a bicycle!

His avocation was music; he was a fine pianist and choral singer. He was active in singing groups, both as pianist and singer. He was charter member of the Schola Cantorum, played in the Two-Piano Society and chamber music groups, and for many years led and sang with the Palo Alto Madrigal Singers. He could play the accompaniment in any key and at the same time, sing any part in a choral work. If you wished to do part of a symphony or opera with him, he would provide, without any score, the full orchestral substance in a flawless structure. He sang the lead in several Gilbert and Sullivan operettas at Stanford, including the judge in "Trial by Jury." He could sing most of the famous "patter" songs by heart at a moment's notice.

John also loved hiking, biking, and golf. He was always upbeat and fun to play with, despite the fact that he wasn't a very good golfer. His golf swing was legendary; he would stand way back from the ball and take two practice swings, pumping his knees up and down; then, without stopping, he would take a third swing, reach out about two feet, and hit the ball. He loved to compete and he was not above using psychological warfare to improve his chances of winning; at a hole over a creek, he would say, "I sure wish I could hit it over this creek like you did last week, and not even worry about the tree limb right above or the thicket just off to the left." He called these bushes "Farquhar's Forest" since he used to worry his former student Bob Farquhar into hitting into those bushes nearly every time they played together.

He was a gentle man with a wry sense of humor, and did amazing and comical imitations of pompous British and Russian politicians and scientists.

During his last year with us, he knew rather accurately the number of days remaining. He used them to enjoy his grandsons, to make new contributions in applied mathematics, to revisit a wide range of music with friends, and to share his gratitude for so full a life.

Above all, he was a generous, cheerful, kind friend to many of us, and we shall miss him very much.

Arthur E. Bryson, Jr., chair
Robert Cannon
Daniel B. DeBra