



Franklin K. Moore

August 24, 1922 – November 21, 2016

Franklin Kingston Moore, the Joseph C. Ford Professor of Mechanical Engineering Emeritus, died November 21, 2016, in Ithaca, where he and his wife Anne ("Nancy"), who survives him, had lived since 1965. Frank and Nancy had recently celebrated their 70th wedding anniversary.

Frank was born August 24, 1922, in Milton, Massachusetts, and grew up in Glen Rock, New Jersey. His lifelong interest in aeronautics began with the construction of numerous model airplanes, and he remembers riding his bicycle to Newark Airport to see Wiley Post's Winnie Mae, the Lockheed aircraft in which Post had accomplished several around-the-world record flights.

After graduating from Ridgewood High School, Frank enrolled at Cornell, beginning a close relationship with the university that lasted the rest of his life. Frank earned his B.S. in mechanical engineering at Cornell in 1944, and then served for two years in the U.S. Army, stationed for most of that time on Adak in the Aleutian Islands.

In 1946 Frank married his high school sweetheart, Nancy Smyth, whom he had met at an Elks Club dance when they both were in the ninth grade. The young couple moved to Ithaca, where they both took classes at Cornell on the GI bill. In 1949 Frank completed his doctorate in aerospace [aeronautical] engineering under the supervision of William R. Sears, and went to work as an aerodynamics research engineer at the NACA Lewis Flight Propulsion Laboratory (currently the NASA John H. Glenn Research Center at Lewis Field) in Cleveland. While at NACA Lewis Frank worked on the problems of screech in rocket engines and rotating stall in turbomachinery compressors, a problem to which he would make major contributions later in his career. He also served as editor of *The Theory of Laminar Flows*, which constituted Volume IV of the highly-regarded *Princeton Series on High-Speed Aerodynamics and Jet Propulsion*.

In 1955 Frank and his family moved to Buffalo, where Frank served as Head, and ultimately Director, of the Aerosciences Division of the Cornell Aeronautical Laboratories. Research in that period at the Aeronautical Laboratories (and elsewhere) focused on hypersonic flight and high-temperature aerodynamics associated with the re-entry into the atmosphere of warheads and, later, Gemini and Apollo capsules. In later years Frank noted that he and others were particularly motivated after October 4, 1957 by the periodic appearance to the naked eye of Sputnik I as it passed over Buffalo in orbit. In 1960, he wrote a paper "Propagation of weak disturbances in a gas subject to relaxation effects" with W. E. Gibson in which they derived a nonlinear equation that now bears their names, the Moore-Gibson-Thompson or M-G-T equation, and is frequently quoted.

In 1965, Frank and Nancy returned to Ithaca and Cornell when he was appointed as the newly-established Joseph C. Ford Professor of Engineering. He taught in Cornell's School of Mechanical and Aerospace Engineering for 28 years, until his retirement in 1993. His research focused on the fundamentals and application of laminar flow boundary layers, an invaluable contribution to NASA's rockets, general aeronautic wing design, and failure issues in turbine design.

In 1984 he was inducted into the National Academy of Engineering, where his citation read "For pioneering fundamental research in fluid mechanics and continuing innovative engineering contributions to power-plant cooling and rotating machinery efficiency." During this time, Frank was a member of a number of national committees concerned with aerodynamics, including the Committee on Microgravity Research, the Committee on Space Science Technology Planning, the Panel on Propulsion, and two terms on the National Research Council's Aeronautics and Space Engineering Board.

In the following year he was awarded NASA's Exceptional Scientific Achievement Medal for his "numerous scientific contributions to the understanding of the fluid mechanics of aeronautics and space propulsion systems."

When Frank moved to Cornell to head the thermal engineering department in mechanical engineering, his interests changed from a focus on aerodynamics to the broader scope of mechanical and thermal engineering. This shift included energy technologies and environmental engineering. He contributed to research on power plant cooling effects on thermal pollution in lakes. The latter involved wind-driven transport, lake recirculation, and stratification and the lake thermal states as it undergoes its annual cycle. He also supervised research on dry cooling towers, a subject of renewed interest because of regions of water scarcity.

Some of Frank's most influential work later in his career illustrated the depth of thinking that he brought to his research. While on sabbatical leave in 1981-82, as the Addison P. Rothrock Visiting Scientist at the NASA Lewis Research Center, he returned to the issues of *rotating stall* and *surge*, aerodynamic instabilities in turbomachinery compressors. In the former, regions of low or reversed flow, known as stall cells, propagate around the compressor annulus, at speeds of from 20 to 50 percent of the rotor speed. The annulus averaged flow is constant in time, but the individual blade passages see a highly unsteady flow that can reverse direction as the stall cells

pass. Surge, on the other hand, is an overall oscillation of the annulus flow, again from reverse flow to high flow. The two phenomena are described here separately, but it is important to realize that they are coupled in a compression system.

On his sabbatical, Frank took a fresh look at the first of these phenomena, rotating stall in multistage compressors. He cast the problem in the framework of a nonlinear *limit cycle*, with the independent variable taken as the circumferential angle around the compressor annulus, rather than time as was typically done. His elegant approach captured, for the first time, the central dynamics of this complex flow field in a simple way—essentially a lumped parameter representation of the actual three-dimensional flow field.

Frank also saw the potential to go further with such models and proposed extending the ideas to the coupled problem—compressor transients that involved both surge and rotating stall. The basic insight was the realization that these could be usefully described without detailed knowledge of the stall and recovery process in the individual compressor blade passages of each stage of the compressor.

In a summer at NASA Lewis, Frank worked with Professor Ed Greitzer of MIT, who was thinking along similar lines. They developed a system of equations that could be solved using dynamical systems theory to predict whether a particular disturbance in the inflow to the machine would result in rotating stall or in surge. The distinction is important for the overall recoverability of the engine from a stall event in which surge is, in fact, the more favorable outcome.

Professor Greitzer's memory is very clear about two items concerning the joint work. The first regards the insights that Frank had in the theory development; there is no ambiguity about the choice of first author in what has come to be known as the 'Moore-Greitzer' theory of compressor stability. Second is the realization that, even though Frank was ten years older, there was no hope of keeping up with him during evening runs along the trails behind the Lewis Center. The ideas that were developed during the collaboration also formed a basis for much successive work in the areas of compressor stall, compressor response to inlet distortion, bifurcation analysis of compression system stability, and active control of rotating stall and surge.

Frank had wide interests and was passionate about many things, engineering science and practice, art, literature, history, music, and athletics. He was a magnetic conversationalist and story-teller. He had a fascinating way with words, and could keep listeners spellbound, often to the point of causing them to lose track of time. Always interested in politics, Frank was a faithful Democrat from Adlai Stevenson on, and he walked door-to-door, campaigning for Barack Obama in 2008. He was a member of the Ithaca Police Commission, served on Ithaca's zoning appeals board, and was a Lansing village trustee.

In the early 1960s Frank rekindled the passion for competitive running he had found as a member of the Cornell cross-country team. He finished the Boston Marathon three times, in 1971, 1972, and 1977. In 2002 he wryly noted that at age 80 he was finally nationally ranked, as the second-fastest runner in the United States in his age group, 80-84. He also cycled competitively and in 1979 won the United States Cycling Federation National Championship

Time Trial race in the Grand Master age group.

Frank loved music and country dancing with Nancy and friends. He could remember the words of songs and poems, quoting Yeats or Willie Nelson at the drop of a hat. He brought his love for Cornell and music to Mechanical and Aerospace Engineering as a founding member of the *Upton Downers*, a barbershop quartet that sang Cornell and Holiday songs at various School functions over the years.

He was a painter, sculptor, and stained-glass artist. He was an avid reader. His knowledge of Native Americans, especially in the northeast, was remarkable. For years he and Nancy joined friends at Big Red football games and Hangar Theater productions. They enjoyed traveling to Europe, the Caribbean, and Ireland, and especially loved small-ship cruises to Alaska, on the Mississippi and St. Lawrence Rivers, and to Costa Rica and the Panama Canal.

In 2011, Frank and Nancy moved to Kendal at Ithaca. Frank took great interest in the woodworking shop and the weekly poetry group. He also enjoyed giving historical talks on such varied topics as the Boston Marathon and President James Garfield.

Frank is survived by his wife, Nancy, and their children David Moore (Barbara Peck), Cathy Moore-Jansen (Peer), Leslie Connors (Jonathan Zisk), Susan Moore (Peter Woodman), Jeffrey Moore (Kathleen), and Jennifer Cibelli (Steven); six grandchildren, and two great-grandchildren. His brother Stanley, his wife Elizabeth, and their children also survive Frank.

Written by Dave Caughey (Chair) and Sidney Leibovich