Jay W. Forrester 1918-2016

Article

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FOREWORD

THIS IS THE TWENTY-SECOND VOLUME in the *Memorial Tributes* series compiled by the National Academy of Engineering as a personal remembrance of the lives and outstanding achievements of its members and foreign members. These volumes are intended to stand as an enduring record of the many contributions of engineers and engineering to the benefit of humankind. In most cases, the authors of the tributes are contemporaries or colleagues who had personal knowledge of the interests and engineering accomplishments of the deceased.

Through its members and foreign members, the Academy carries out the responsibilities for which it was established in 1964 as an organization of outstanding engineers. Members are elected by their peers on the basis of significant contributions to engineering theory, practice, and literature or for exceptional accomplishments in the pioneering of new and developing fields of technology. The National Academies of Sciences, Engineering, and Medicine share a responsibility to advise the federal government on matters of science, technology, and medicine. The expertise and credibility that the National Academy of Engineering brings to that task stem directly from the abilities, interests, and achievements of our members and foreign members—our colleagues and friends—whose special gifts we remember in these pages.

Julia M. Phillips
Home Secretary

Memorial Tributes

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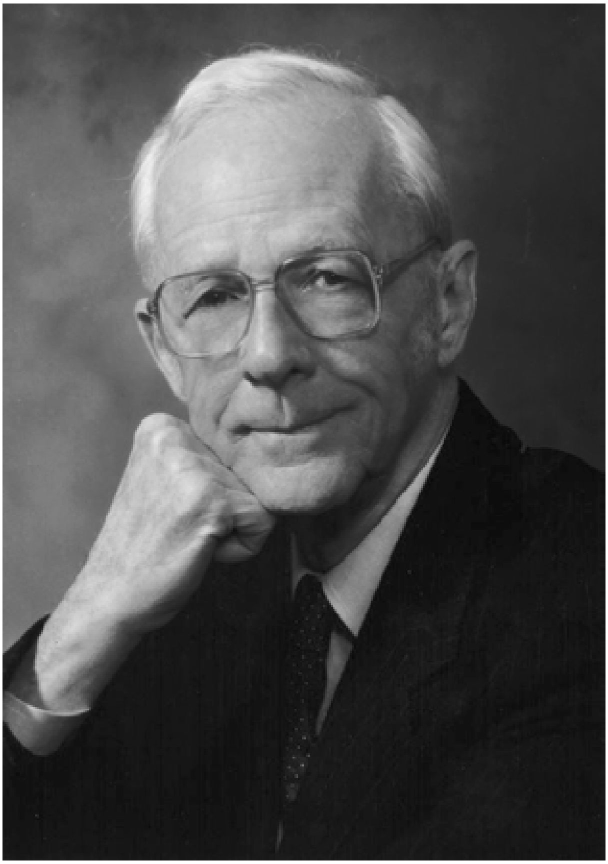


Jay W Forrester

JAY W. FORRESTER

1918–2016

Elected in 1967

"Design and development of magnetic core memory devices."

BY DAVID LANE AND JOHN STERMAN
SUBMITTED BY THE NAE HOME SECRETARY

JAY WRIGHT FORRESTER, a pioneer in digital computation and management information systems, creator of the system dynamics computer simulation method, and Germeshausen Professor Emeritus at the Massachusetts Institute of Technology, died November 16, 2016, at the age of 98.

He was born July 14, 1918, on a cattle ranch near Climax, Nebraska, where his parents were homesteaders in one of the last areas of the plains to be settled. He was taught at home by his mother for his first two years of schooling. After that, he rode his horse each day to a one-room schoolhouse.

Jay developed an early interest in electricity, tinkering with batteries, doorbells, and telegraphs. Growing up on a remote ranch offered many opportunities to get his hands dirty finding practical solutions to important problems, such as building a wind-powered generator to provide the first electricity at the ranch. Offered a scholarship to an agricultural college, he decided that the life bucolic was not for him and instead enrolled at the University of Nebraska–Lincoln, where he earned his bachelor's degree in electrical engineering in 1939.

After graduation he went to MIT, where he worked with Gordon Brown, the servomechanism pioneer who later became MIT's dean of engineering. He received his master's degree in electrical engineering in 1945 for his thesis "Hydraulic Servomechanism Developments."

During World War II, Jay designed and built a novel feedback control servo to stabilize radar antennae on naval ships, travelling to Pearl Harbor in 1943 to install his prototype on the aircraft carrier *Lexington*. Though a civilian he volunteered, when the fleet was ordered to sea, to stay aboard to ensure that the servo—and thus the ship's radar—worked. During that mission, the *Lexington* participated in retaking the Marshall Islands and survived a torpedo strike.

Concurrent with these efforts Jay was associate director of MIT's Servomechanisms Laboratory (1940–51). He directed the Airplane Stability and Control Analyzer (ASCA) project, aimed at developing flight simulators to test new aircraft designs. The ASCA was originally envisioned as an analog computer, but Jay realized that the nonlinear dynamics of aircraft could not be realized with analog components and began to explore the potential for digital simulation.

He visited the computing centers at Harvard and the University of Pennsylvania's Moore School of Electrical Engineering, where he met John von Neumann and J. Presper Eckert, who were then developing the ENIAC. These visits convinced Jay that ASCA would be based on digital computation, a bold decision given that digital computers at the time were far too slow and unreliable to meet the requirements of ASCA.

Jay led the development of the Whirlwind computer, for years the only machine fast enough and reliable enough for real-time tasks such as simulation of complex dynamical systems like aircraft or numeric control of machine tools. Computer memory quickly emerged as a major bottleneck in the development of Whirlwind. Memory cost $1 per bit per month. To solve the storage problem, in 1949 Jay invented and won the patent for coincident-current magnetic core memory. Core memory—cheap, stable, reliable—became the industry standard for decades and flew to the moon in the computers on the Apollo missions.

Whirlwind became the central element of the Semi-Automatic Ground Environment (SAGE) system and the first computer produced in volume. Built to defend North America from Soviet bomber attack, SAGE consisted of a network of digital computers and long-distance communication systems that sent target-tracking information from radar stations to computers. The computers in each center processed the data and computed flight plan vectors for interceptor aircraft and missiles. This demanding real-time application required high reliability, an immense challenge since each of the several dozen SAGE centers contained about 80,000 vacuum tubes.

Jay's legendary drive for quality led him to improve the design and manufacturing processes, making SAGE one of the most reliable command-and-control systems ever built: when the last center was decommissioned in 1983, the systemwide uptime over two and a half decades of service was 99.8 percent. Jay's colleagues and students during this period went on to major accomplishments: Robert Everett, his second in command on the Whirlwind project, went on to lead the MITRE Corporation, and student Kenneth Olson cofounded the Digital Equipment Corporation.

For his pioneering innovations in digital computing Jay was elected to the NAE in 1967. His many other honors include the Valdemar Poulsen Gold Medal (1969), IEEE Medal of Honor (1972) and Pioneer Award (1990), induction to the National Inventors Hall of Fame (1979), and the Presidential Medal of Technology (1989, with Bob Everett).

By the mid-1950s, Jay, ever seeking new frontiers, felt that "the pioneering days in computers were over." His work with servomechanisms, Whirlwind, and SAGE provided extensive experience managing complex organizations, and in 1956 he joined the faculty of the new MIT Sloan School of Management. In a memo that year, "Dynamic Models of Economic Systems and Industrial Organizations," he described his vision for the synthesis of feedback control theory with digital simulation to understand and improve complex human systems.

Jay's first dynamic model explained the large fluctuations in production, inventories, headcount, and profit in the appliance division of General Electric. Observing how the different departments were run, Jay learned how managers, from the retail level through distribution channels and in factories, responded to the information locally available to them as they tried to control their piece of the organization. Rather than attribute fluctuations to exogenous events, he saw the appliance business as a system of interacting units in which managers in each link in the supply chain responded in a locally rational fashion to the incentives and information they faced. He saw how these decisions interacted in a system consisting of multiple, nonlinear feedbacks to generate unwanted, costly fluctuations. The work launched the field of supply chain management, today a core discipline in operations research and management.

Jay's unique contribution, detailed in his 1961 book *Industrial Dynamics* (Productivity Press), was to develop concepts about systems, feedback, control, and dynamics that were previously restricted to engineering and physical contexts into a rigorous yet practical method for what he called "enterprise design… [finding] management policies and organizational structures that lead to greater success" (p. 449).

Jay believed that a manager's role is not only captain of the ship but also designer of the ship. Success required both rigorous scientific modeling and close engagement with managers and other stakeholders.

Throughout the 1960s Jay and his students applied system dynamics to a growing range of problems, yielding major contributions to both management science and practical impact. Toward the end of the decade the work increasingly turned to public policy issues and the more general term "system dynamics" replaced "industrial dynamics."

In his 1969 book *Urban Dynamics* (MIT Press), Jay developed a novel model of the processes underlying the development, stagnation, decline, and recovery of cities. The project began when the former mayor of Boston, John F. Collins, became a visiting professor at MIT with an office next to Jay's. In the mayor's struggles with urban problems, Jay recognized the same policy resistance and unintended consequences he had observed in corporations. *Urban Dynamics* explained why so many policies intended to alleviate urban poverty failed or made the problem worse. Although it was enormously controversial at the time, subsequent events have shown his analysis to be largely correct.

In 1970, after attending a meeting of the Club of Rome, Jay created a model of the interactions of population, industrialization, natural resources, and pollution. His book *World Dynamics* (Wright-Allen Press, 1971) again provoked enormous controversy—and launched the field of global modeling. Developments since have only underscored the importance of Jay's insights. Growth of population and material production on a finite planet must eventually cease. In the meantime, long delays in the response of the economy and technology to resource depletion and environmental degradation could lead human activity to overshoot the planet's "carrying capacity." As he put it,

> Attacking symptoms rather than underlying causes will be futile…. Growing population and industrialization will overwhelm the short-term efforts if we do not restrain these forces that are exceeding the carrying capacity of the Earth.[1]

A stark warning, yet Jay's simulations also showed how innovation, demographic changes, and policies voluntarily limiting the growth of material production could, together, build a healthy, sustainable society.

System dynamics coalesced into an academic field in the 1970s, with programs at universities around the world. Jay's work in this area was recognized with many awards, including induction into the International Federation of Operational Research Societies' Hall of Fame and many honorary degrees. In 1986, IBM's Thomas J. Watson Jr. endowed the Jay W. Forrester Chair in Management at MIT in recognition of the vital role of Jay's work in the success of IBM.

Jay formally retired in 1989, an event he said "had no effect whatsoever on my work." He dedicated much of his time

[1] Quoted on p. 379 in Lane D, Sterman J. 2011. *Profiles in Operations Research: Pioneers and Innovators*, ed. Gass S, Assad A. New York: Springer.

thereafter to catalyzing the education of young people in the principles of systems, leading to the introduction of dynamic modeling in schools throughout the United States.

Jay believed that teachers are not the source of answers but should be guides and coaches who help learners develop the inquiry skills and capabilities they will need to make a difference in a world of growing complexity and dynamism. His theory of change is fundamentally optimistic and empowering. He believed that everyone can gain an appreciation for the complex dynamics of natural and human systems, and then use those insights to create a better world.

In person, he was faultlessly courteous, and at the same time direct and unambiguous with criticism (and praise). He was hospitable and convivial, enjoying a good joke and quick to share humorous stories.

Jay's wife of 64 years, Susan Swett Forrester, died in 2010. They are survived by their children Judith, Nathan, and Ned as well as grandchildren and great-grandchildren.

From the Sandhills of Nebraska to the MIT Servomechanisms Laboratory, from the *Lexington* to the creation of the computer age, from *Industrial Dynamics* to *World Dynamics*, from corporate boardrooms to elementary school classrooms, Jay Forrester lived his entire life on the frontier.