Engineers and Scientists: Similarities and Differences

by Dr. Henry Petroski, P.E., New York Xi '63

It is an irony that engineering gets less-frequent and less-explicit public recognition than science, for it is engineering and not science that has a direct influence on our daily lives, on our comfort, and on our standard of living. There is little immediate impact of the scientific discovery of a new physical phenomenon or a new chemical element. Such events are newsworthy in themselves, of course, but they may or may not ultimately influence our lives. The real but often unstated significance of a discovery is its potential engineering promise in the form of new electronic devices or new materials. Little of the "benefit on mankind" that chemical engineer Alfred Nobel wished to honor derives from a disembodied physical phenomenon or the addition of the name of a new element to the periodic table. These are certainly intellectual and scientific achievements of the first order, but in themselves they do not necessarily benefit that most abundant segment of mankind that is seeking to raise itself toward the status of the developed countries, where achievement is measured not in scientific theories but in engineering realities.

Engineering was not always the neglected sibling. In nineteenth-century Britain, engineers were heroes. It was engineers who had given the developed world, at least, its canals, railroads, steamships, the telegraph, sanitation, electric light, and inventions and gadgets galore. The Victorian engineer was held up as a model not only of industry and invention but also of honesty and goodwill. Samuel Smiles's hagiographies of the likes of George and Robert Stephenson, who brought intercity railroads to Britain and so changed the way people traveled, were collectively known as *Lives of the Engineers*. Smiles's *Lives* went through numerous editions, some appearing even as late as the early twentieth century, providing clear evidence that his stories of achievement and virtue were read and read widely.

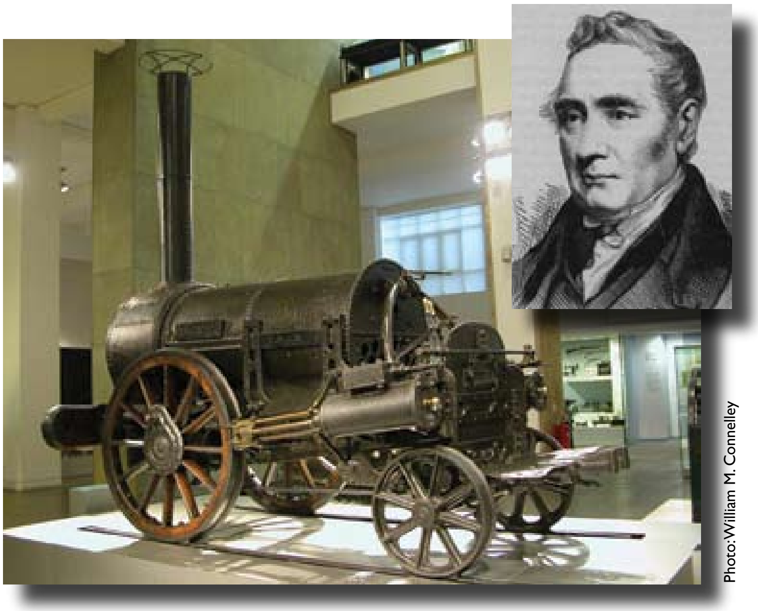


Photo: William M. Connelley

The pioneering rocket locomotive built in 1929, and inspired by George Stephenson, inset, is shown preserved at the Science Museum in London.

Heyday of Engineering

Today, British engineers look back forlornly at their nineteenth-century counterparts and what they see as the heyday of engineering in the context of society. In his president's address before a meeting of the Institution of Structural Engineers, David I. Blockley, among his many accomplishments a most thoughtful theorist of engineering, described a common lament among contemporary British engineers, namely, that "even very able engineers sometimes feel it necessary to apologize for themselves and say, when faced with anything remotely outside their field, 'I'm only an engineer'."[1]

Science as we know it today was in fact threatened by engineering in the late-nineteenth and early-twentieth centuries—not a little because of the celebration of the Victorian engineers specifically and of engineering and technology generally in the pages of the likes of *Scientific American*. Given the overwhelming benefits that came from inventions like the telegraph, telephone, electric light and power, and radio, science seemed at best to be the handmaiden of engineering. After all, it was the Industrial (and not the Scientific) Revolution that so raised the standard of living in the Western world. The scientific coup of capturing the prizes endowed by the engineer Nobel was emblematic of how science strove for recognition at the time. The development of the atomic bomb crowned a decades-long struggle of scientists to win victory over the engineers. They did it by having more egocentric personalities, more gentlemanly influence in Washington and the academy and in society generally, and by scaring the world.

Being the entrenched dominant and more visible class that they are, it is no wonder that scientists—mad, egghead, or otherwise—fare better in newspapers and in the polls than engineers. One can speculate on the reasons. Scientists and advocates of science engage in their own kind of public relations. The efforts of the National Science Foundation to explain "how basic research reaps unexpected rewards" can be viewed as falling into this category. By providing examples of how basic research—unmotivated other than by being science for science's sake—can ultimately produce advances in health care, public safety, and other incontrovertibly important areas, the audience might be said to be conditioned to have a high tolerance for scientific research, no matter how abstract or metaphorical. By repeating the conventional wisdom that "scientific discovery makes invention possible,"[2] a director of the NSF reinforced the seeming primacy of science over engineering and all other technological endeavors.

It is an old joke among engineers that when newspapers report some positive technological achievement—like a successful rocket launching or the safe landing of an interplanetary probe—it is attributed to scientists. When something negative happens—like a rocket exploding on the launch pad or a probe going astray or otherwise malfunctioning—it is the engineers who are blamed. In a story about a promising new fusion method, scientists were credited with achieving thermonuclear fusion with a blast of X-rays. The method was described as potentially simpler than that of using magnetic fields to compress hydrogen, but admittedly the new method presented "an engineering challenge that scientists have only begun to think about." After describing alternative approaches to solving the engineering problem, the conclusion was that to choose among them, "We definitely need more physics." Though elaborating on the engineering problem, whose solution holds great promise for producing electrical power, the story on the new fusion method had not one mention of engineers.[3] Like all generalizations, this view of how the press treats scientists and engineers differently is not invariably true, but it occurs often enough for it to have a subtle and cumulative effect on public opinion.

Slide Rule Set

There have been some indications that things may be changing, in engineering and elsewhere in society. A newspaper feature, which appeared remarkably in the house-and-home section of the *New York Times*, ran under the headline, "Slide-Rule Set, Nameless No More," with the sub-heading declaring that "The elegant poetics of engineering creates a new model for home building." One New York engineer, Guy Nordenson, who has collaborated with architects, is described as a "Renaissance nerd," giving the normally pejorative term a new twist. By way of explanation, the author described engineers who, in their younger years at least, played flamenco guitar, raced bicycles, and who still quote Rainer Maria Rilke and Ezra Pound. While some of the Renaissance nerds eschew the mantle of celebrity engineer, others embrace it, "determined to recast the image of the engineer in the more exciting role of inventor."[4]

Not surprisingly, among the engineers described in the *New York Times* piece is the engineer-architect-artist Santiago Calatrava, who, evoking Le Corbusier's remark that a building is a machine to live in, was quoted as saying, "A building is a sculpture you walk into." Calatrava's structures graced Europe long before they reached America. But his first project in the U.S.—the Milwaukee Art Museum addition—with its dynamic *brise soleil* that unfolds like a bird's wings to shade the structure from the sun—was a resounding success. Described as a "poet-engineer and architect," Calatrava is the kind of individual who can single-handedly change the public image and the self-image of the engineer.

But in fact the world has long been familiar with engineers like Calatrava, who is in the tradition of the Swiss

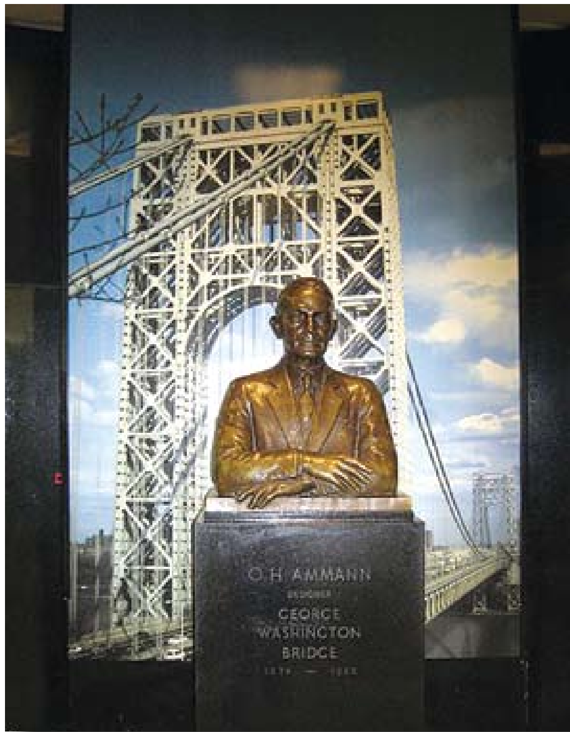


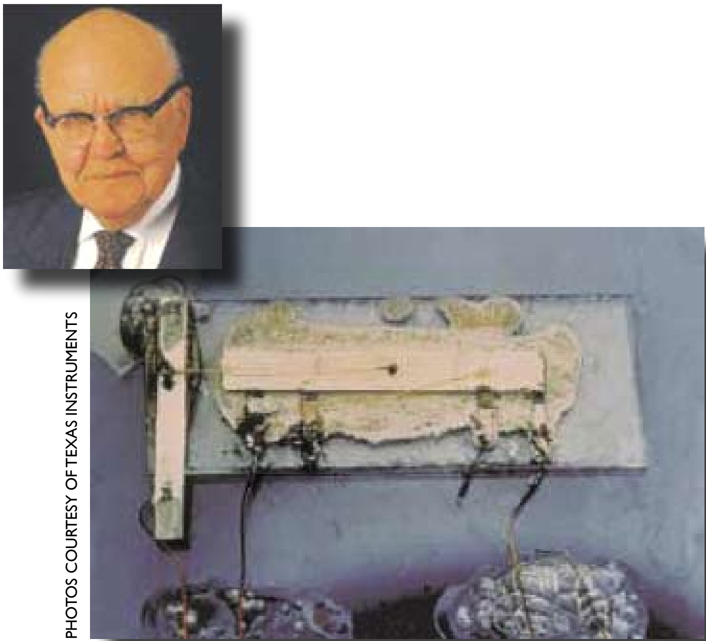
Photo: Jim Henderson

A bust of bridge builder and Tau Bate Othmar H. Ammann at the George Washington Bridge bus station in New York.

bridge builders Robert Maillart and Christian Menn, whose work has been the subject of an exhibition curated by David P. Billington for the Princeton Art Museum. Billington's classic book, *The Tower and the Bridge: The New Art of Structural Engineering*,[5] is an excellent introduction to the values of engineering, as is his brilliantly innovative, *The Innovators: The Engineering Pioneers who Made America Modern*,[6] which presents engineering in the social context in which it always must work, showing that the equations used by nerds, enlightened or not, necessarily have embedded in them the values of society.

The value-laden achievements of engineers like Eiffel and Maillart, and Menn and Calatrava, whose careers and whose works collectively span more than a century, belie the fear that there is a crisis in engineering. In fact, there always have been and we can expect that there always will be engineers who rise above the rest and excel. America has had its John Roebling and James Buchanan Eads and Othmar H. Ammann, *New York Epsilon '02,* and a host of other giants of design and construction. Acknowledging them raises the issue of the great-man theory of history, which has fallen out of fashion, but the reality is that the process of conceiving and carrying out a great engineering project takes a leader, a visionary, an entrepreneur, an innovator, a great man or woman—now that women are no longer discouraged from joining the profession.

It is no accident that it is bridge builders who come most immediately to mind when thinking and speaking about engineering and art and values—and visibility. Bridges are pure engineering structures. Their form and their function are one. They need no great façade or other architectural embellishment, though chief engineers sometimes do hire architects as consultants. That is not to say that architec-



PHOTOS COURTESY OF TEXAS INSTRUMENTS

FIRST INTEGRATED CIRCUIT: Jack S. Kilby, *IL A '47*, inset, invented the integrated circuit at Texas Instruments in 1958. Comprised of only a transistor and other components on a slice of germanium, Kilby's invention, 7/16-by-1/16-inches in size, revolutionized the electronics industry.

tural details, embellishments, and accidents do not make a difference in bridge building. The Golden Gate Bridge would not likely be the iconic success that it is were it not for its art deco architectural theme and the wisely chosen color of its paint. In an analogous way, the overall appearance of New York's Bronx-Whitestone Bridge benefits greatly from the sleek architectural treatment of its massive anchorages. Though architects did contribute to the appearance of such bridges, it was always the chief engineer who chose the architect—as he did the assistant engineers—and made the final decision as to what architectural and engineering advice to accept or reject and at what time to curtail calculations and begin building.[7]

There are many masterpieces of structural art among the bridges of America, and not all of them are the work of widely known engineers. Numerous bridges on the Oregon coast highway, for example, are the work of state bridge engineer Conde B. McCullough, *Iowa Alpha 1910*. Constructed mostly during the 1930s, they are without peer in the genre of the reinforced concrete arch. The Sunshine Skyway Bridge across Tampa Bay, perhaps until recently the most well-known and widely-recognized cable-stayed bridge in America, was the work of the late Eugene C. Figg, *South Carolina Gamma '58*, who also designed the spectacular soaring concrete arch carrying the Natchez Trace Parkway across a quiet Tennessee highway. Among the newest high-profile cable-stayed bridges in America is the awkwardly named but beautifully lighted Leonard P. Zakim Bunker Hill Bridge across the Charles River. This engineering achievement seems to serve as the signature backdrop for virtually every television interview that takes place in Boston, a subtle reminder of an upstaged profession.

The differences in self-image and expectations between scientists and engineers are perhaps nowhere so striking as in how they view the world and their place in it. Scientists, especially those who deal directly with the mysteries of the universe, must certainly have big egos and feel a strong sense of self-worth. How else could they presume that they can discover fundamental laws of nature and unlock secrets that have been kept since the beginnings of time? Even the most ambitious and self-confident of engineers, those who direct great projects that result in the longest bridge or the tallest skyscraper in the world or who produce the smallest machines or the strongest materials, seldom claim to understand everything that they do. Whenever they work on the frontiers of technology, engineers invoke the art of engineering and engineering judgment to carry their work across the gaps in scientific knowledge about whatever it is they might be doing. Humble engineers ultimately invoke and apply a factor of safety to their designs, effectively coating them with a buffer of protection from the unknown or unknowable.

Jack S. Kilby, *Illinois Alpha '47*, is one of the few engineers to be awarded a Nobel prize—in physics in 2000 for his 1958 invention of the integrated circuit—which occurred shortly after he joined the staff of Texas Instruments to do research in miniaturization. Following his early success, he, like many others in the fledgling semiconductor industry, was looking for applications for the chips of silicon that have been called stone circuits. In 1965, in the more managerial role that successful engineers tend to rise to, Kilby summoned some engineers into his office and told them that he and the president of Texas Instruments had been talking, and what they wanted the company's engineers to come up with was "some kind of personal computer." This was when digital computers were still room-sized and mechanical desk calculators were the size of typewriters and had the look of cash registers. What Kilby described to his engineers was unheard of—a computer no bigger than the book on his desk, something that could fit in his pocket and operate on batteries. It had to have some buttons or other means of inputting a problem it was to solve, and it had to have some lights or some other display to announce a solution. Kilby called the thing a "slide-rule computer."[8]

Back to the Drawing Board

The product Kilby described was without precedent. According to one of the engineers who was at the meeting, after Kilby laid out what was wanted, "There was probably not more than 10 seconds of silence, because engineers don't laugh at absurdities. When you tell 'em you want to do something, they just give it their best shot."[9] The project became known by the code name *Cal Tech*, and two years later Kilby's engineers presented him with "a black aluminum box studded with numbered keys the size of sugar cubes, the whole assembly closer in bulk to a hardcover than a paperback."[10] The result, "the world's first cordless, portable calculator," disappointed the president of Texas Instruments because it was not what he envisioned as being capable of launching integrated circuits into the mass marketplace. The engineers were sent back to their drawing boards and, after three years, during which time microchips shrank in size and advanced in computing power, the company released its first electronic scientific calculator—at a price ($350) that may have been extraordinarily high for everyday consumers but not for scientists and engineers who immediately saw its advantages.

Neither scientists nor engineers can just will into existence a solution to a problem, but engineers always have the advantage in finding one. Scientists and engineers are bound by the same laws of nature, the same building blocks of the universe, and the same methods of inquiry. But, in addition, engineers have the advantage of seeking something to make rather than just explaining what is already made. If there is no chemical element between potassium and calcium (atomic numbers 19 and 20, respectively), chemists cannot make one in the laboratory. However, if there is no bridge between New York and New Jersey, engineers can (and did) design and construct one. According to Willy Ley, writing in the visionary *Engineers' Dreams*, "the word fantastic, when applied to engineering, merely means 'it has not yet been done.' "[11]

Engineers frequently invoke aerodynamicist Dr. Theodor von Kármán's, *California Beta '02*, oft-quoted distinction between scientists and engineers: "The scientist seeks to understand what is; the engineer seeks to create what never was." The only camp from which I have heard objections to this distinction is the chemists, especially synthetic chemists. Granted, a chemist synthesizing something that was theretofore unknown in nature is creating what never was. Yet most chemists no more want to be described as engineers than real engineers want to be described as scientists, our engineering educational system notwithstanding.

We can extricate ourselves from the apparent dilemma presented by von Kármán's dichotomy in a simple way. The "pure" scientist may indeed seek to understand the given universe and its various components, and the "real" engineer may seek to create things that are not found in nature. However, the apparent scientist/engineer duality is in fact a continuum, with von Kármán's distinction being only a caricature. The overwhelming majority of scientists and engineers move freely back and forth along the continuum of seeking truth in nature and seeking beauty in things.

Laws of Nature

Everything made, whether by scientists or engineers, may be considered natural in the sense that it ultimately consists of the fundamental chemical elements and is wholly compatible with the laws of nature. We laugh at perpetual-motion machines precisely because they purport to violate the basic laws of thermodynamics, and we recognize how absurd it is to think that anyone can seriously believe those laws can be violated by some clever manipulation of components, materials, and processes. The term artificial and synthetic are often used in a pejorative sense in opposition to natural. In fact, everything is natural in the sense that it is made up of ingredients and formed of processes that come from and comply with the laws of nature. We really are using the term natural as shorthand for naturally occurring. But even here, we misrepresent the reality. Cotton may be said to be a natural fabric, but cotton shirts do not occur in nature. They are the product of harvesting, ginning, dying, spinning, weaving, sewing, and, perhaps the most unnatural of all processes, marketing. If cotton feels better to wear than polyester, then so be it, but it is not necessarily because cotton is more natural than polyester.

Another form in which von Kármán's distinction is often presented is as follows: "Science studies what is; engineering creates what never was." This anthropomorphizing of the activities of science and engineering is usually considered to make the same point as the distinction between scientists and engineers. In fact, that is not at all the case, and therein lies a further confusion between scientists and engineers. Scientists can indeed have as their motivating goal the understanding of nature, of what is, but that is not to say that they always pursue that goal exclusively. Sometimes, in order to gain further insight into some naturally occurring substance or process, they have to design an experiment or a piece of apparatus or an instrument that enables them to carry their investigation forward. Similarly, engineers may indeed wish to create things that do not occur in nature, but that is not to say that they are always engaged directly in that pursuit. Sometimes, in order to make an advance toward their goal of a new machine or process, they have to go off on a tangent in order to gain a more complete understanding of some impediment that stands in the way of their objective. This is what the Wright brothers had to do when they could find no scientific theory on which to base the shape of a wing or propeller. Mechanical engineer Dr.

It's all rocket engineering! The April 12, 1981, launch at Pad 39A of STS-1, just seconds past 7 a.m., carried astronauts John W. Young, *Georgia Alpha '52*, and Robert L. Crippen, *Texas Alpha '60*, into an earth orbital mission scheduled to last for 54 hours, ending with an unpowered landing at Edwards Air Force Base, CA. *Photo: NASA*

Simon Ostrach, *Ohio Alpha '44*, whom NASA has recognized as one of a dozen "superstars of modern aeronautics," has argued for an R&D process—which he designates R4D—in which a design is the ultimate goal and scientific research is conducted in service to that goal.[12]

When scientists and engineers do deviate from the ideal distinctions made by von Kármán, they in effect move away from the ends and toward the middle of the continuum on which they operate. When scientists depart from pure science, they engage in a sort of engineering; when engineers deviate from pure engineering, they engage in a sort of science—that known as engineering science. In other words, scientists can and do engage in engineering, and engineers can and do engage in science. The two lines of thinking about von Kármán's distinction—defined by the scientist/engineer and the science/engineering endpoints—are not really parallel but orthogonal. The continuum between scientist and engineer and the one between science and engineering are two dimensional, and the activities of scientists and engineers engaged in a project can be plotted as points on the plane defined by the scientist-engineer and science-engineering axes.

If we can overcome our habit of thinking of the left side of the line of abscissas as negative and the lower portion of the line of ordinates as negative, we can plot points describing scientists and engineers engaged in scientific and engineering activities without prejudging either to be positive or negative, good or bad, better or worse, depending on the quadrant in which they fall. A plot of points representing all sorts of activities of scientists and engineers is likely to look more like data coming from a random-number generator than lying on a deterministic graph.

The fact of the matter is that virtually all scientists do engineering and all engineers do science to varying degrees at various times in their careers. During World War II, scientists working on the Manhattan Project engaged in considerable engineering, represented by points located in the second quadrant. Engineers working on the same project no doubt collaborated with scientists to engage in activities deep in the fourth quadrant. Indeed, the plot of all points representing the scientific and engineering activities of all scientists and engineers would likely occupy those quadrants with a much greater frequency than they did the first and third, where scientists performing science and engineers doing engineering would be located.

Same Basic Problem

In some instances, the same basic problem attracts scientists and engineers equally. The engineering science of fluid dynamics, which is applicable to a wide range of phenomena, "from the turbulent flow of cosmic jets to the sound raindrops make when they strike the surface of a lake," was recently the focus of a newspaper article. "The apparent simplicity of fluid dynamics is an illusion. Scientists and engineers," the reporter went on, giving both camps equal billing, "have been struggling to understand the behavior of flowing fluids—which can be liquids or gases, but also piles of sand or heaps of mixed nuts—for centuries, but mysteries in the field still remain." Such mysteries can account for the spontaneous failure of grain hoppers or the disintegration of a space shuttle returning to the earth's atmosphere. It takes scientists and engineers, engaged in pursuits called science and engineering, working together to solve those mysteries and thus make water flow more smoothly from a pitcher or air move more silently and effectively to ventilate a room.[13]

If significant progress is to be made in solving more earth-shaking problems that of late have been the focus of attention everywhere from the mass media to peer-reviewed journals of science and engineering, then it behooves scientists and engineers to understand each other as well as themselves and their respective and cooperative roles in the larger scheme of things. The solution of global problems relating to climate, energy, security, the environment, and the world economy requires global thinking. Engineers and scientists are perfectly capable of such thinking, but it must be done in the context of a synergistic approach to the complimentary scientific and engineering goals of understanding the world as it is and seeking to change it for the better.

Endnotes:

[1] D.I. Blockley, "Thinking Outside of the Box, with Phil's Eight New Maxims," *The Structural Engineer* 79: 22-29 (16 October 2001), pp. 23-24.

[2] National Science Foundation, *How Basic Research Reaps Unexpected Rewards* (Washington, DC: National Science Foundation, 1980), pp. i-ii.

[3] Kenneth Chang, "New Fusion Method Offers Hope of New Energy Source," *New York Times*, April 8, 2003, p. F2.

[4] Julie V. Iovine, "Slide-Rule Set, Nameless No More," *New York Times*, January 30, 2003, pp. D1, D7.

[5] David P. Billington, *The Tower and the Bridge: The New Art of Structural Engineering* (New York: Basic Books, 1983).

[6] David P. Billington, *The Innovators: The Engineering Pioneers who Made America Modern* (New York: Wiley, 1996).

[7] For another view, see John van der Zee, *The Gate: The True Story of the Design and Construction of the Golden Gate Bridge.* (New York: Simon & Schuster, 1986).

[8] Jerry D. Merryman, as quoted in Jeffrey Zygmont, *Microchip: An Idea, Its Genesis, and the Revolution It Created.* (Cambridge, MA: Perseus, 2003), p. 86.

[9] *Ibid.*

[10] *Ibid.*, p. 92.

[11] Willy Ley, *Engineers' Dreams*. Revised edition (New York: Viking Press, 1954), p. 16.

[12] Simon Ostrach, "Microgravity and the Human Exploration of Space Technology Challenges," *Technology in Society*, Vol. 30, issues 3-4 (August-November 2008): pp. 411-414.

[13] Bruce Schechter, "From Flowing Fluids, Beautiful Images and Unlocked Secrets," *New York Times*, June 24, 2003, p. F3.

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