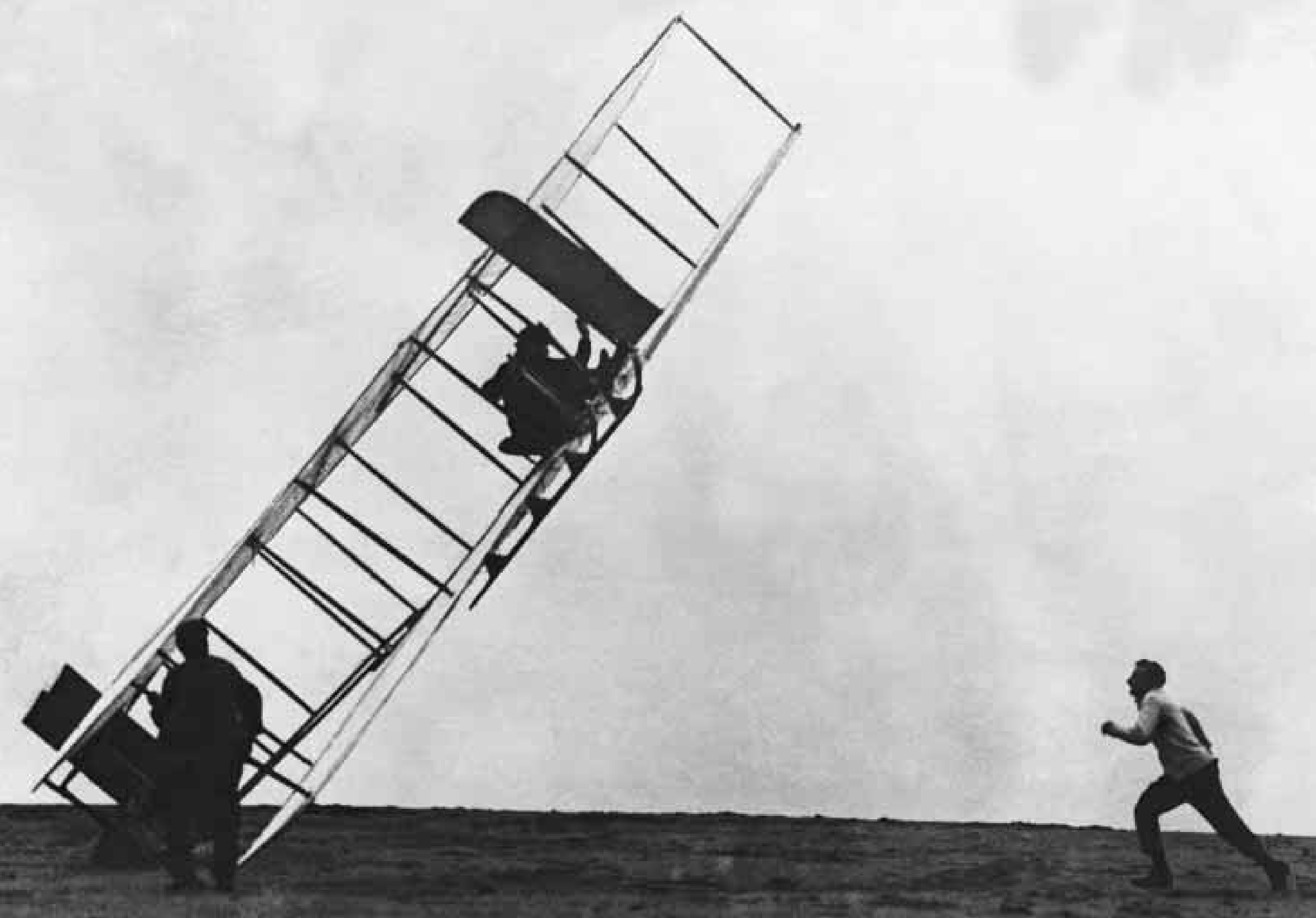
The Hubris of Extreme Engineering

by Henry Petroski



Wright brothers at Kitty Hawk, N.C., 1903

> "Engineers can come to **believe in themselves** and their creations beyond reasonable limits. When failures do occur, they naturally cause setbacks but usually do not force the abandonment of dreams for ever grander and more ambitious projects."

The ancient Greek mathematician and engineer Archimedes claimed that he could move Earth with a large lever, if only he could locate a fulcrum and a place to stand. Many centuries later Galileo was more circumspect about what engineers can do, for he recognized that what worked on a small scale did not necessarily succeed on a larger one. By then, Renaissance engineers knew that levers, like stone obelisks and wooden ships, could be scaled up only so much before they broke under their own weight. Unfortunately, what Galileo learned has not always been remembered, nor is it likely always to be respected in the new millennium.

With the introduction of iron as a structural material, it was possible for engineers not only to dream of larger and larger structures but also to realize them. The first iron bridge, completed in 1779, spanned 100 feet (30 meters) across the Severn River in western England. Within decades, spans exceeding 500 feet were being envisioned, and soon the railroad created the need for ever longer iron bridges.

Isambard Kingdom Brunel, the great Victorian engineer known as the "Little Giant," was famous for his expansive thinking. Although his contemporaries saw his Great Western Railway serving the countryside to Land's End (the westernmost point of England), Brunel saw it continuing on across the Atlantic in the form of a steamship carrying passengers and cargo to America. His ship, the *Great Western,* became one of the first to disprove the conventional scientific wisdom of the time—that no ship could be built large enough to carry all the coal it needed for such a voyage.

If the Atlantic could be crossed, then why not greater expanses of sea? Brunel designed his *Great Eastern* steamship to be large enough to transport all the coal it would need to voyage from England to Australia. At 692 feet, the ship had to be constructed parallel to the water because the shipyard could not accommodate the conventional stern-first orientation for assembly and launching. The launch itself took three embarrassing months when the massive vessel got stuck on the incline into the water. Although the ship was structurally sound, it proved too large for most harbors and ended up a white elephant, eventually cut up for scrap. A larger ship was not to be built for almost half a century, until the 704-foot *Oceanic* was completed in 1899.

This pattern has repeated itself—for instance, the supersonic Concorde, first built in the mid-1970s, is a technologically sweet aircraft but has seen only limited service because its sonic boom is not welcome over residential areas around airports. Other supersonic projects have been abandoned as a result. Clearly, the designs of engineers must be more than just strong enough and fast enough; they must also be compatible with the existing phys-

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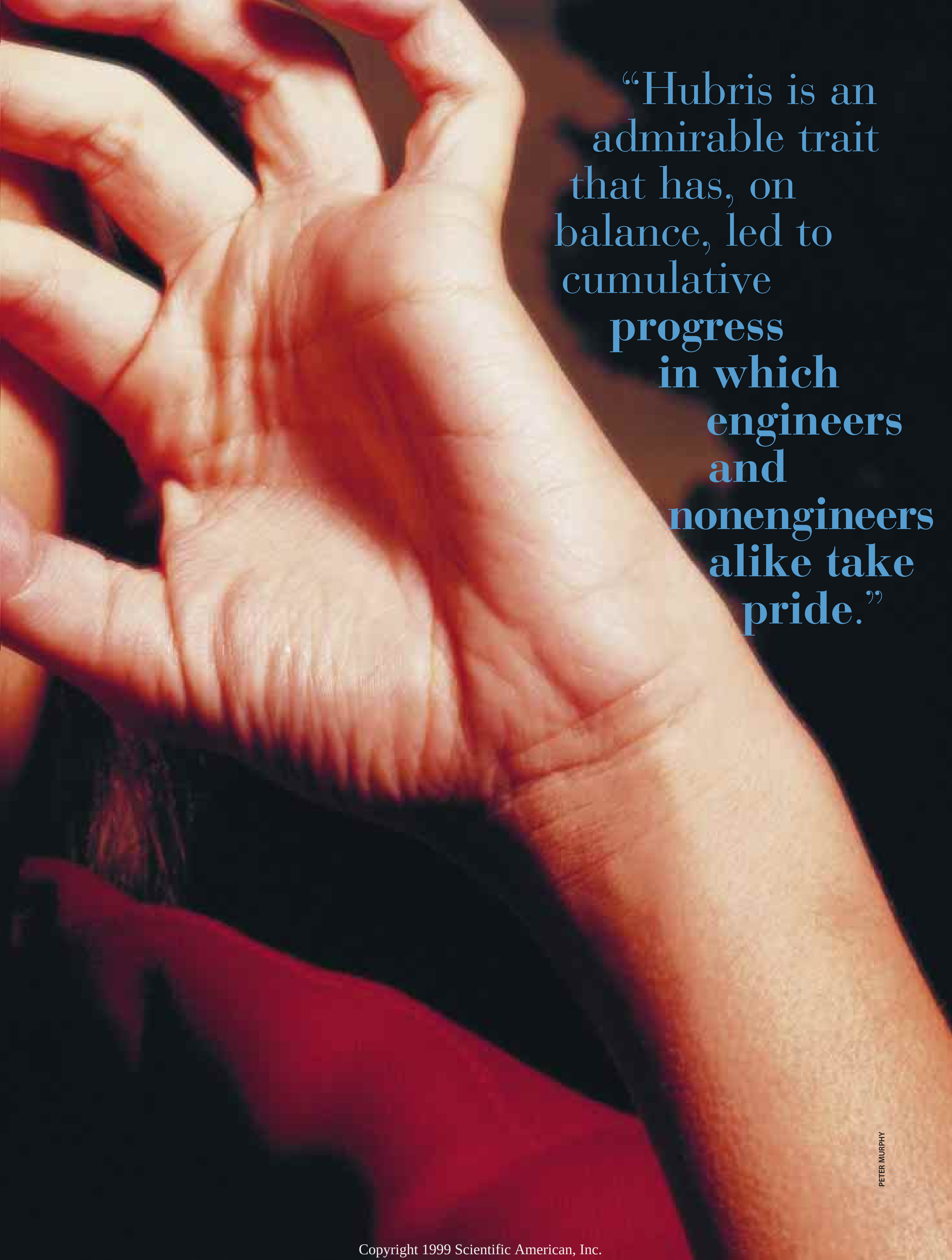
YANN ARTHUS-BERTRAND *Corbis*

"Colossal accidents happen when

Abandoned town near Chornobyl, November 1998

overconfidence and complacency prevail."

The Motorola 7400 Power PC microprocessor, currently the fastest on the market



“Hubris is an admirable trait that has, on balance, led to cumulative **progress in which engineers and nonengineers alike take pride.**”

PETER MURPHY

“Clearly, the designs of engineers
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Demolition of public housing projects in Chicago, December 12, 1998

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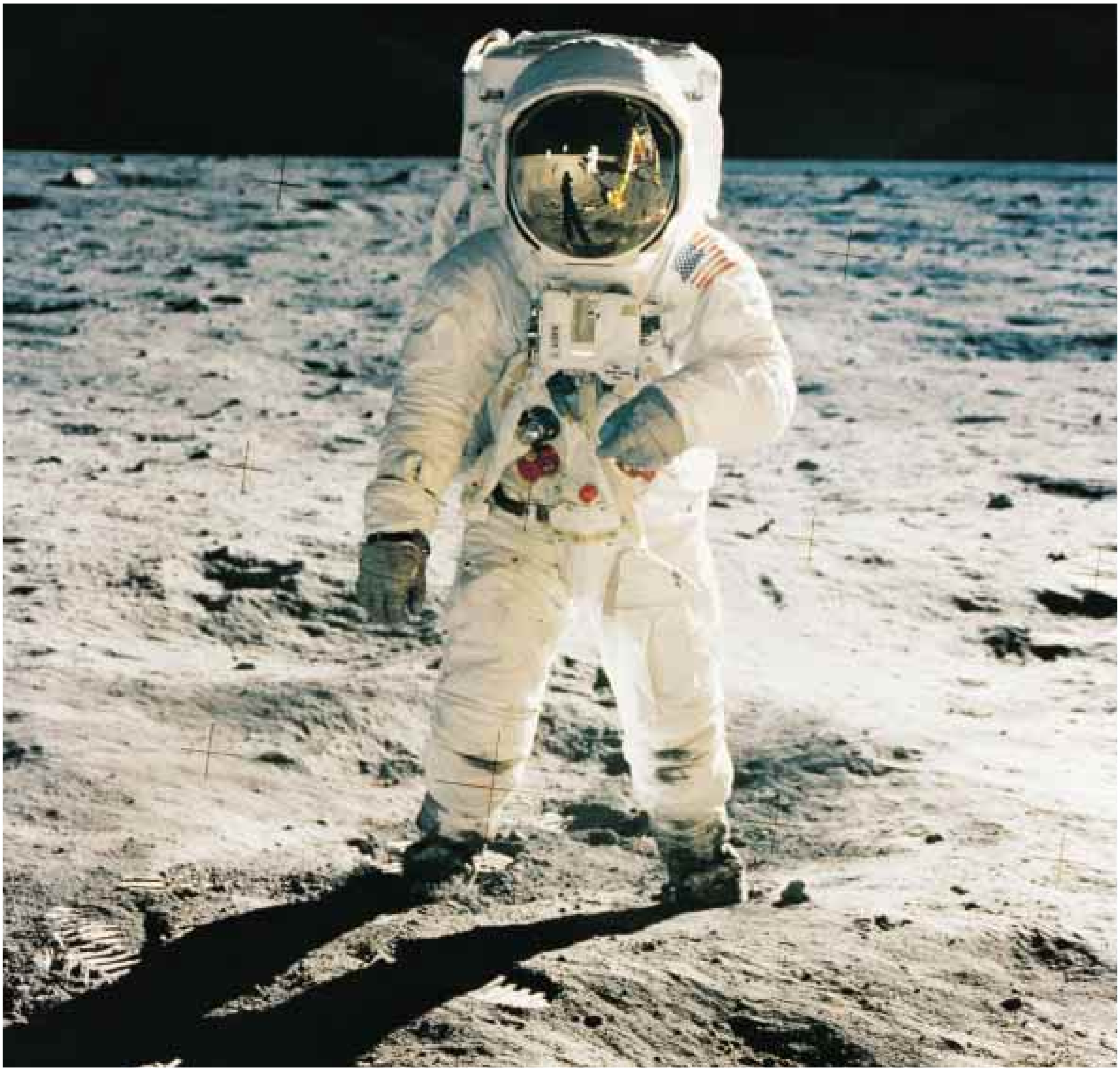

NEIL A. ARMSTRONG/NASA

Astronaut Edwin “Buzz” Aldrin on the moon, July 20, 1969

as it is to **probe the universe further** and the atom deeper than our ancestors did.”

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ical, political and social infrastructure.

When Gustav Lindenthal, who had built an impressive bridge in Pittsburgh in the early 1880s, proposed an enormous suspension bridge across the Hudson River at New York City in 1885, there were plenty of naysayers (as there always are with great projects). At 3,500 feet, the bridge's span was to be over twice that of the Brooklyn Bridge, then the longest in the world. And some people, perhaps recalling Galileo's caveats, raised the legitimate question of whether such a long span could even support itself. Yet Lindenthal held on to his dream for almost 40 years, modifying it as times and circumstances changed. Its price tag also changed with the times, rising to as high as $500 million when land acquisition and terminal facilities were included, a price that no one seemed willing to pay. To his critics who said that such a massive bridge could not be built, Lindenthal responded that "it was possible to bridge the Atlantic Ocean, but impossible to finance such an undertaking."

Although Lindenthal's great bridge was never built as he had dreamed it, a more modest crossing of the Hudson was engineered by his assistant Othmar Ammann, whom Lindenthal accused of not thinking monumentally enough and of being a disloyal protégé. But if Ammann's bridge did not live up to Lindenthal's aesthetic expectations, it did to more practical ones: at one tenth the cost of Lindenthal's monstrosity, the George Washington Bridge, which opened to traffic in 1931, was such a technological and financial success that in the following decade it served as a sleek model for suspension bridges built across the U.S., including the Golden Gate Bridge in San Francisco.

The ill-fated Tacoma Narrows Bridge, another descendant of Ammann's George Washington Bridge, was completed in 1940 across an arm of Puget Sound south of Seattle. At the time it was the third longest bridge in the world and narrower than any before it. The bridge had been designed according to a theory developed by Leon Moisseiff, who had served as consulting engineer to the project, as he had to virtually all large suspension bridges built after 1900. When a lesser-known engineer questioned the design as too slender, Moisseiff stood by his theory, assuring people that the bridge would be safe.

Only three months after it opened, however, the Tacoma Narrows Bridge collapsed in a 42-mile-an-hour wind. The physical phenomenon of aerodynamic instability, which had not revealed itself in heavier and wider bridges, dominated the behavior of the Tacoma Narrows. In the aftermath of this disaster, mid-20th-century engineers responded by proposing more comprehensive theories of bridge behavior. Today suspension bridges more than twice as long as the Tacoma Narrows are built safely, in no small part due to the lessons learned from the initial catastrophe. The recently completed Akashi-Kaikyo Bridge in Japan spans 6,529 feet—a mile and a quarter—between its towers.

This is not to say, though, that the hubris of bridge engineers will never again draw them into the same trap that led to failures in the past. In the 1990s, after decades of successful experience with cable-stayed bridges, beginning with those built in Germany after the war, significantly longer spans began to be built. Even though cable-stayed bridges were originally meant to span no more than 1,200 feet, with longer crossings expected to be suspension bridges, two modern cable-stayed bridges—the Pont de Normandie in France and the Tatara Bridge in Japan—now extend over as great distances as the Tacoma Narrows suspension bridge did.

How far cable-stayed bridges can be scaled up before they, too, reach their limit depends on how well engineers understand the behavior of their structures. Already some concern has arisen, because excessive movement has been observed in the taut cables of cable-stayed bridges in Sydney, Australia, and elsewhere during strong wind and rain. Thus far such problems have been conquered by retrofitting the bridges with damping devices, which prevent the movements from growing out of control, but the hubris of bridge engineers that drives them to build longer spans in the face of these warning signs may yet lead to uncontrollable conditions.

Engineers also manifest their hubris in other types of projects. Willy Ley, in his 1954 book *Engineers' Dreams,* described some of the grandest schemes imagined by engineers up until that time: damming the Congo River to create the largest lake in Africa; draining the Mediterranean Sea to reclaim land for crowded Europe; building a tunnel between England and France. This last dream was, of course, realized when the Channel Tunnel opened in 1994, more than two centuries after the idea was first articulated by French engineer Nicolas Desmaret. Whereas the Congo is not likely to be dammed in the foreseeable future, the Three Gorges Dam in China will soon back up water on the Yangtze River and displace more than a million people. Today the decision whether to dam a river is often more political than technical. Engineers can dream, but it takes political savvy and resolve, not to mention money, to move the machinery that moves the earth.

The ultimate triumph of mega-engineering schemes, from gigantic ships to monumental skyscrapers, is also frequently limited by issues tangential to the main idea, by details that can seem decidedly low-tech or even nontechnical—matters such as politics, aesthetics and safety. When engineers ignore these factors or treat them as undeserving of the same careful analysis as the main technological challenge, disaster can result. The sinking of the *Titanic* might not have been nearly as great a tragedy had the ship's vulnerability been acknowledged by having enough lifeboats on board. The Three Mile Island and Chornobyl accidents might not have progressed to the point that they did had nuclear power generation not come to be viewed as so commonplace as to breed a casual and careless attitude among some operators. The space shuttle *Challenger* might not have exploded had managers

Chrysler Building, New York City, completed 1930

JOSEPH POBERESKIN *Tony Stone Images*

"Just as by standing on the shoulders of giants we can become even bigger giants, so it is that by climbing on the spires of skyscrapers, **engineers can reach for ever taller skyscrapers.**"

heeded engineers' warnings about the behavior of O-rings in cold weather, rather than becoming emboldened by the two dozen successful space shuttle missions that preceded Flight 51L. In short, colossal accidents happen when overconfidence and complacency prevail.

Engineers and managers of technology, being human, can come to believe in themselves and their creations beyond reasonable limits. When failures do occur, they naturally cause setbacks but usually do not force the abandonment of dreams for ever grander and more ambitious projects. As soon as the cause of a failed effort is sufficiently understood and the sting of its tragedy sufficiently remote, engineers want to pick up where they left off in their pursuit of greater goals. This is as it should be in engineering—as in life—for it is as much a part of the human spirit to build longer and to fly faster as it is to probe the universe further and the atom deeper than our ancestors did. Just as by standing on the shoulders of giants we can become even bigger giants, so it is that by climbing on the spires of skyscrapers, engineers can reach for ever taller skyscrapers. If this be hubris, it is an admirable trait that has, on balance, led to cumulative progress in which engineers and nonengineers alike take pride. SA

About the Author

HENRY PETROSKI is Aleksandar S. Vesić Professor of Civil Engineering and professor of history at Duke University. He is the author of *To Engineer Is Human* and *Engineers of Dreams,* among other titles. His latest work, *The Book on the Bookshelf,* is about the care and housing of books themselves.