

# Contents

*List of Sidebars* ix

*List of Figures* xi

*Preface* xv

*Acknowledgments* xxi

CHAPTER ONE	The World's Fairs of 1876 and 1939	1
CHAPTER TWO	Edison, Westinghouse, and Electric Power	13
CHAPTER THREE	Bell and the Telephone	35
CHAPTER FOUR	Burton, Houdry, and the Refining of Oil	57
CHAPTER FIVE	Ford, Sloan, and the Automobile	79
CHAPTER SIX	The Wright Brothers and the Airplane	103
CHAPTER SEVEN	Radio: From Hertz to Armstrong	129
CHAPTER EIGHT	Ammann and the George Washington Bridge	155
CHAPTER NINE	Eastwood, Tedesko, and Reinforced Concrete	176
CHAPTER TEN	Streamlining: Chrysler and Douglas	199
APPENDIX	The Edison Dynamo and the Parallel Circuit	220
	<i>Notes</i>	223
	<i>Index</i>	257

## CHAPTER ONE

# The World's Fairs of 1876 and 1939

**O**n a much-anticipated trip in 1939, a family of four drove from the Philadelphia suburbs up U.S. Route 1 into New Jersey and then turned east through the dark overpasses of Weehawken. Suddenly the road began a sweeping circle to the right, and over the left parapet, lit by the afternoon summer sun, appeared the skyline of Manhattan with the towers of the Empire State and Chrysler buildings and Rockefeller Center. Soon the car descended into the three-year-old Lincoln Tunnel before emerging in New York City itself. The senior author (age twelve) and his brother (age ten) had their first view of New York City on the way to Flushing Meadow, site of the 1939 New York World's Fair. But first they checked into the Victoria Hotel in Manhattan where they were transferred to somewhere in the sky—probably the thirtieth floor—with a view they had never before experienced. They were in the skyline.

The next morning the family drove to the fair and went to the most popular exhibit, the Futurama ride in the General Motors pavilion, also named Highways and Horizons.<sup>1</sup> Although they were early, there was already a line longer than either preteen could see. But they were fresh, and finally their turn came. Into the cushioned seats they nestled, and a smooth voice guided them through an incredible landscape of highways, skyscrapers, parks, cities, factories, and forests, all in miniature and all seen from above as if in a low flying airplane (figures 1.1 and 1.2). The unforgettable sixteen minutes in the grip of Norman Bel Geddes, the industrial designer, surpassed all of the other impressions of the fair. It was the future. Even in youth one could sense the central themes of mobility, speed, and adventure—an urban frontier of new cities and new sceneries. Children of the Depression, the senior author and his brother had traveled very little and had led simple lives; their parents would often point to the impressive stone building in Narberth, Pennsylvania, where they had lost all their savings in the bank crisis. The bank lobby was now a beauty salon.

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*The World's Fairs*  
of 1876 and 1939  
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Figure 1.1. James and David Billington at the 1939 New York World's Fair. Source: Billington family album.

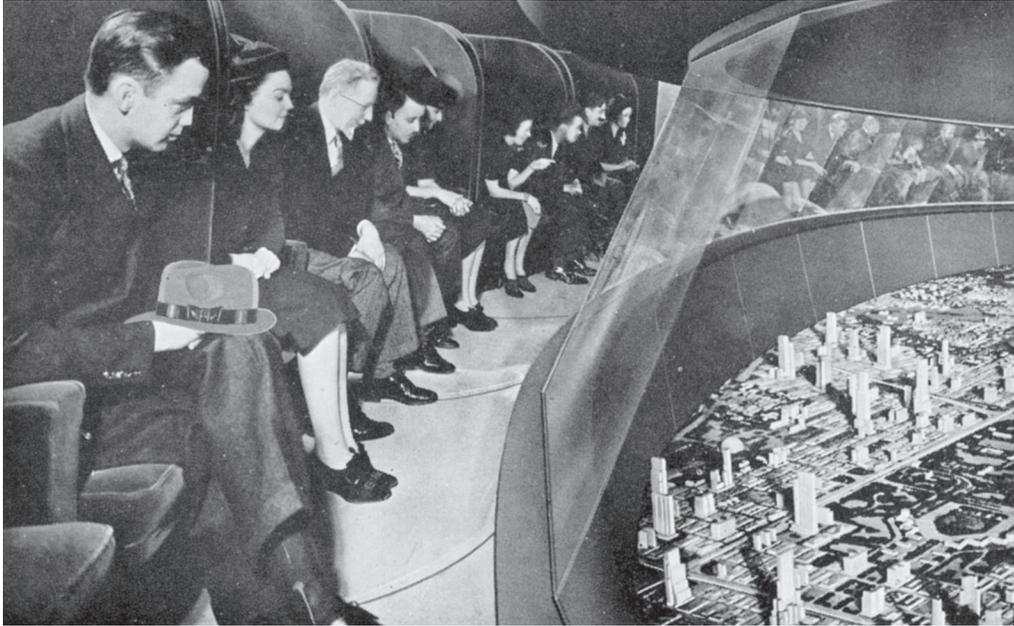


Figure 1.2. The Futurama ride at the 1939 General Motors pavilion. Courtesy of Professor Andrew Wood, San Jose State University, and General Motors.

Those who remember the Futurama ride have lived to see it realized as they circle above any major airport today. There below are the superhighways, the tiny cars, the skyscraper cities, and the vast suburbs. In 1939 this civilization could be glimpsed; a generation later it was reality. Yet the 1939 New York World's Fair was not just a vision of the future; it portrayed a technology and a society already in existence. The cars, highways, buildings, and industries that Bel Geddes portrayed were familiar objects. The Futurama ride was a celebration of steel and concrete, oil and cars, flight and radio, and above all electric power and light—the great industrial innovations of the late nineteenth and early twentieth centuries.

Before these transformative changes, America was a mostly rural society. People lived close to nature and prosperity depended on the harvest. Technology was simple: most houses were built out of wood or stone, firewood supplied fuel, candles gave light, and tools and equipment were made of wood and iron. Local transport was by horse or

horse-drawn carriage over unpaved roads. Life was slow-paced, and communication—for those who could read and write—was by letter. But the steamboat and then the railroad and the telegraph had begun to reduce isolation and to accelerate the pace of American life. An earlier world's fair, the Philadelphia Centennial Exhibition of 1876, celebrated these changes and foreshadowed even greater ones to come.

On May 10, 1876, the “United States International Exhibition” opened in Fairmount Park, Philadelphia. The fair commemorated the one hundredth anniversary of the American Revolution and came to be known as “The Centennial.” Large halls dedicated to horticulture and crafts reflected a nation that was still largely rural and self-sufficient. But the principal attraction of the fair, Machinery Hall, displayed the products of new industries that were beginning to remake society. At the center of Machinery Hall stood the Corliss steam engine, thirty-nine feet high. President Ulysses S. Grant and the visiting Emperor Dom Pedro of Brazil inaugurated the fair by turning on the engine: its two giant pistons turned a huge wheel that powered other machinery in the hall. Built by George Corliss of Providence, Rhode Island, the great engine was the ultimate expression of the steam engineering that had led the first hundred years of America's industrial growth (figure 1.3).<sup>2</sup>

The first working steam engine was invented by Thomas Newcomen in 1712. Steam from a separate boiler entered a cylinder on one side of a piston. Applying cold water condensed the steam and created a partial vacuum. Atmospheric pressure on the other side then pushed the piston and pulled a rocking beam, enabling the engine to pump water from mines. In 1769 James Watt created a separate condenser that allowed the temperature of the cylinder to remain relatively constant. Watt's engine could perform the work of the best Newcomen engines with about one-third of the fuel.

Watt soon designed a version of his engine to turn wheels, providing rotary motion to run factories. Belts connected to the wheels of steam engines soon began turning grain mills, weaving looms, machine tools, and other equipment. Early factories in America did not at first need steam power. Water from nearby rivers gave Francis Lowell and other New England manufacturers the power they needed to create a major new textile industry. By the late nineteenth century, though, many factories had shifted to steam. The Corliss engine on display in Philadelphia was one of the largest rotary steam engines ever built.

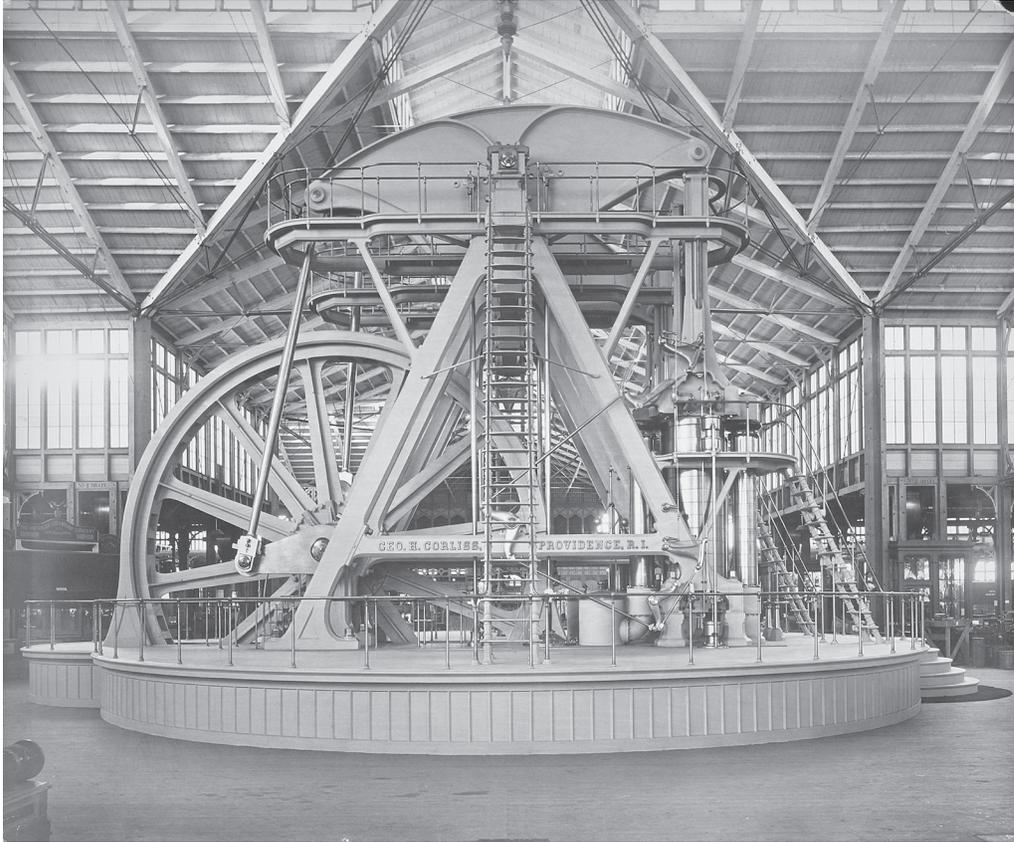


Figure 1.3. The Corliss engine at the 1876 Philadelphia Centennial Fair. Courtesy of the Print and Picture Collection, Philadelphia Free Library. Circulating File.

The greatest contribution of steam was not to drive engines in place but to power mobile engines on boats and trains. The first great American engineering innovation, Robert Fulton's *Clermont* steamboat, proved itself in an 1807 trip up the Hudson River from New York to Albany. Steamboats soon opened the Mississippi and Ohio rivers to commerce, creating the world captured by Mark Twain, who began his own career as a steamboat pilot. Ocean going steamships soon carried much larger quantities of goods over long distances. More influential still was the railroad. George and Robert Stephenson of England built locomotives in the 1820s that used steam under high

pressure to push pistons directly. During the 1830s and 1840s, railroads and steam locomotives revolutionized transportation in Britain and spread to the United States and other countries. In the 1850s J. Edgar Thomson, chief engineer and later president of the Pennsylvania Railroad, built a rail line across the Allegheny Mountains that brought the U.S. rail network to the Midwest. A transcontinental railway connected the two coasts of the United States in 1869. Locomotives designed by Matthias Baldwin of Philadelphia carried much of nineteenth-century America's rail traffic and Baldwin locomotives were prominent at the 1876 Centennial (figure 1.4).

But the 1876 fair marked the high point of the reciprocating steam engine and the beginning of its decline, for a new kind of engine made its first public appearance in Philadelphia that summer. Developed by the German engineer Niklaus Otto, the new engine also employed piston strokes. However, instead of burning fuel in a separate boiler to produce steam, Otto's engine burned fuel directly in a piston cylinder, pushing the piston head in a series of timed combustions. In the 1880s engineers began to use such internal-combustion engines to power automobiles, and in the first two decades of the twentieth century, Henry Ford made an automobile with such an engine that was rugged and cheap enough to reach a mass market. The Ford Model T and other mass-produced cars released transportation from the confines of the rail network and gave a sense of personal freedom to Americans that would define their way of life in the new century.

The Otto engine burned coal gas but internal-combustion engines soon ran on gasoline, a distillate of petroleum. Petroleum refining had grown in the 1850s to supply kerosene, another distillate of crude oil, to indoor lamps for burning as a source of light. Kerosene provided a better illuminant than candles and was more abundant than whale oil. The drilling of underground crude oil deposits in western Pennsylvania in 1859 brought a rush of small drillers and refiners to the region. John D. Rockefeller's Standard Oil Company of Cleveland, Ohio, soon dominated the industry, growing from a local refiner in 1870 into a national monopoly a decade later. Standard Oil's market for kerosene gradually declined as electric power spread and made indoor electric lights an alternative to kerosene. But the automobile would give the oil refining industry a new and even greater market in the twentieth century.

The year of the Centennial was the year Thomas Edison set up his research laboratory at Menlo Park, New Jersey. His greatest inventions were still in the future: the

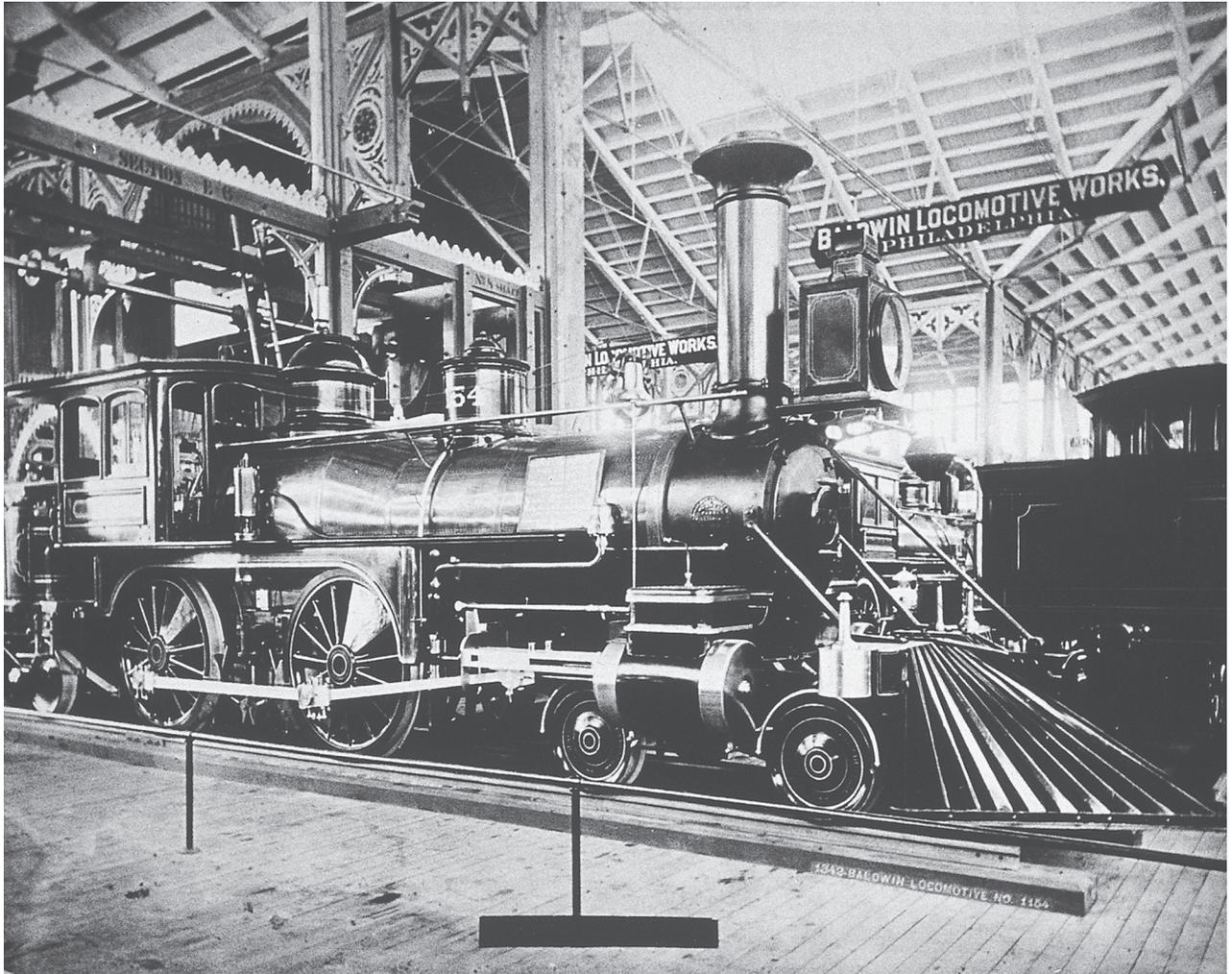


Figure 1.4. Baldwin locomotive at the Centennial Fair. Courtesy of the Print and Picture Collection, Philadelphia Free Library. No. II-1342.

phonograph (1877), the carbon telephone transmitter (1877), an efficient incandescent light (1879), and the electric power network to supply it (1882). But by 1876 Edison had established a reputation as an inventor through improvements he had made to the electric telegraph. Developed in the 1830s and 1840s by Samuel F. B. Morse, the telegraph revolutionized communications in the nineteenth century. One company,

Western Union, dominated long-distance telegraphy by the 1870s. The Philadelphia Centennial fair had its own telegraph office, and telegraph devices, lines, and poles were on display. Yet the Centennial marked the high point of the telegraph too, for it was at the Philadelphia fair that Alexander Graham Bell gave his first public demonstration of a telephone. With the telegraph, messages had to be sent and received in offices by trained operators and then delivered by messengers. The telephone permitted instant two-way communication by voice. Bell's company eventually replaced Western Union as the telecommunications giant of the United States, and daily life in the twentieth century would come to depend on the telephone as much as on the car.

Like Edison, Andrew Carnegie was a telegraph operator early in his career. Carnegie rose in the 1850s from telegrapher in the Pittsburgh office of the Pennsylvania Railroad to manager of the office himself. Striking out on his own, he left the railroad in 1865 to form the Keystone Bridge Company, which built bridges across the Ohio and other rivers. Models of Keystone bridges were on display at the Centennial (figure 1.5). The enormous market for steel soon induced Carnegie to manufacture it, and he built the world's largest steel plant near Pittsburgh in 1875. He sold his firm to the New York banker J. P. Morgan in 1901, who merged it with rivals to create the first great twentieth-century corporation, United States Steel. Steel made possible the tall skyscraper buildings and long-span bridges that reshaped the cities and landscape of the twentieth century.

These breakthroughs were not the only technically significant events of the late nineteenth and early twentieth centuries. But the telephone, the electric power network, oil refining, the automobile and the airplane, radio, and new structures in steel and concrete were the innovations that set the twentieth century apart from the nineteenth. Some of these innovations and the individuals who conceived them are more familiar than others: most Americans have heard of Bell and the telephone but few will have heard of Othmar Ammann, whose George Washington Bridge connected New York to New Jersey in 1931 and became the model for large suspension bridges. This book describes these innovators and their work.

The book also explains innovations in engineering terms. Modern engineering can be grouped into four basic kinds of works: structures, machines, networks, and processes. A *structure* is an object, like a bridge or a building, that works by standing still. A

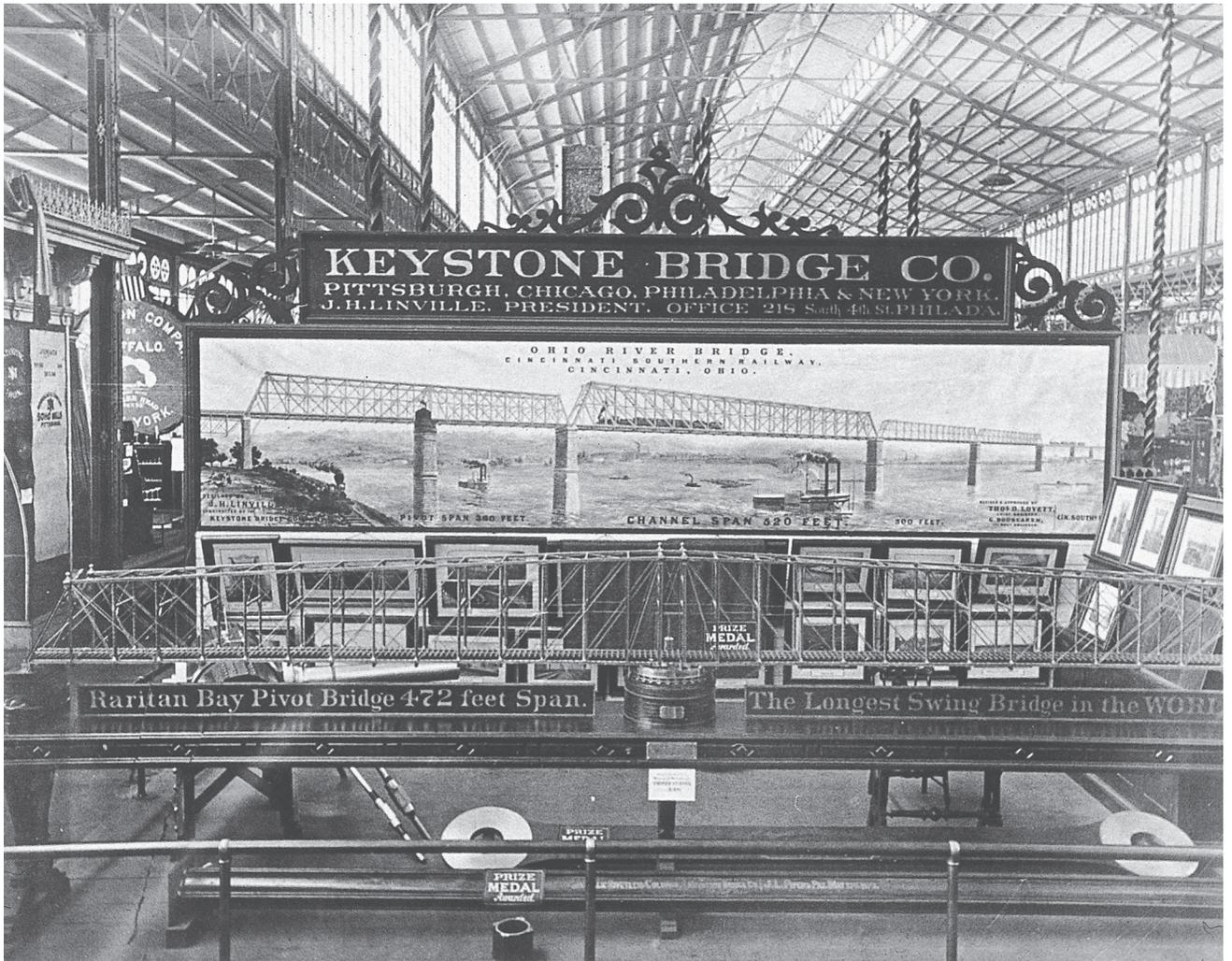


Figure 1.5. Keystone Bridge Company exhibit at the Centennial Fair. Courtesy of the Print and Picture Collection, Philadelphia Free Library. No. III-2339.

*machine* is an object, such as a car, that works by moving or by having parts that move. A *network* is a system that operates by transmission, in which something that begins at one end is received with minimal loss at the other end (e.g., the telephone system). Finally, a *process* operates by transmutation, in which something that enters one end is changed into something different at the other end (e.g., oil refining). We will see that

many innovations are combinations of these four ideas. With structure, machine, network, and process as a basic vocabulary, complex objects and systems can be understood in terms of their essential features.

Engineers describe their works with numbers, and certain numerical relationships or formulas characterize the key engineering works of the late nineteenth and early twentieth centuries. These formulas do not explain any object or system in detail; professional engineers today would use more complex mathematics to analyze and design things. But the formulas in this book each convey the basic idea of a key work and enable the reader to think about great works of technology as engineers would think about them. In this way, the reader can enter into the imagination of the designers and can understand the basic choices that went into a design.

The Model T automobile of 1908 is an example. The car's engine had four cylinders, each containing a piston attached to a single crankshaft underneath the engine. In a timed sequence, gasoline entered each cylinder for ignition and the combustion pushed each piston downward and turned the crankshaft. Another shaft running the length of the car transmitted the rotary motion to the axles and the wheels. A simple relationship expressed by the formula  $PLAN/33,000$  represents this activity and gives the *indicated horsepower* of the engine. Combustion creates a pressure  $P$  (in pounds per square inch) on the head of the piston in each cylinder. The piston travels down the length  $L$  of the cylinder (in feet). The area of the piston head  $A$  (in square inches) and the number of power strokes per minute  $N$  provide other essential information, and dividing by 33,000 gives the indicated horsepower. The formula expresses the basic working of the car's engine. In chapter 5, we give the  $PLAN$  numbers for the Model T and explain how the car was efficient for the needs and conditions of the time.

A suspension bridge has no moving parts but can be explained by a formula that relates its weight and size. A suspension bridge typically has two towers that carry a roadway deck from cables anchored on each side of the bridge. The weight of the deck and of traffic on the cables tend to pull the towers inward and must be resisted by the anchorages. This resistance is called the *horizontal force*. It can be calculated in pounds by multiplying the weight on each cable  $q$  (in pounds per foot of length) by the square of the length  $L$  between the tower tops (in feet) and then dividing by eight times the depth  $d$ , the vertical distance (in feet) from the midspan of the deck to the level of the

tower tops. We explain in chapter 8 how Othmar Ammann used the relationship  $qL^2/8d$  in his design of the George Washington Bridge.

The *PLAN* formula did not begin with the automobile; James Watt devised it to measure the horsepower of a piston steam engine. The bridge formula also goes back to the early nineteenth century, when Thomas Telford designed the first modern iron arch and cable bridges with it. These formulas show that earlier engineering ideas often find new forms and uses, but never lose their relevance. The engineering ideas we present from the past are still fundamental to technology today.

But numerical relationships are not just matters of calculation. They involve choices. A car can be designed to be expensive or affordable, rugged or stylish. A bridge can hold up its weight with a design that is costly or economical, ugly or elegant. The best engineers strive for more than just efficiency. They value economy in the cost of making and operating an object or system, and when the needs of efficiency and economy are met, they look if possible for elegance.

Many of the engineers in our book were opposed by experts immersed in established technologies and ways of doing things. Thomas Edison challenged engineering authorities who did not think his system of light and power was scientifically possible. Unlike professional telegraph engineers, who believed that what society needed were more efficient forms of telegraphy, Alexander Graham Bell saw the potential of a telephone. William Burton faced the opposition of the Standard Oil directors, who saw no need for a more efficient way to obtain gasoline from oil, and Henry Ford had to overcome investors who believed that reaping profits from the small market for luxury cars made more sense than producing an affordable car to serve a mass market. The Smithsonian Institution for many years denied the Wright brothers credit for inventing the airplane, and in his efforts to combine safety and elegance in dam design, John Eastwood had to struggle against a narrow engineering opinion that looked for safety in massive works.

In some cases, though, the innovators were the problem. Edison clung to his system of electric power distribution using direct current, giving George Westinghouse the opportunity to create a market for alternating current that eventually became the standard for household use. Ford stuck to producing his successful Model T, giving General Motors and Chrysler the opportunity to establish themselves by supplying a

greater variety of cars. The Wright brothers failed as entrepreneurs because they could not abandon their original airplane design to compete with better ones that other engineers soon developed. Edwin Howard Armstrong won a lawsuit against his rival Lee de Forest over a key radio patent. But Armstrong demanded payment that his rival could not make, allowing the case to remain open and so giving later judges the chance to rule in favor of de Forest. The structural designer Othmar Ammann achieved revolutionary economy in the design of the George Washington Bridge, but he also embraced a theory of how the bridge worked that neglected the dynamic effects of wind. The Tacoma Narrows Bridge, designed by another engineer according to the theory, came down in moderate winds in 1940. The difficulties that many engineers faced after their great innovations did not diminish their achievements but reveal the misjudgments that often followed success.

The chapters that follow are primarily about the engineering ideas that helped launch the twentieth century. Each idea was usually simple in its original form; as each new technology began to mature, it became more complex. At the same time, each branch of engineering developed in its own unique way. The networks and machines of the period from 1876 to 1939 propelled their inventors to public acclaim because their work went directly into the homes and garages of ordinary Americans. Process industry was more mysterious; refined in private compounds, shipped to filling stations, and then pumped into cars, gasoline was rarely seen and the engineers who produced it were almost unknown to the outside world. Great bridges were conspicuous landmarks, yet their designers and the innovators in steel and concrete were also largely invisible. Modern engineering often presents two faces: one familiar and iconic, the other anonymous and drab. This book tries to bring the great names down to earth, by making their ideas numerically or conceptually more accessible, while bringing to light the lesser-known engineers whose work still gives shape to modern life today.

# Index

*References to sidebars' pages are listed in bold type*

- Ader, Clement, 238n3
- aerodromes, 106–7, 120, 124. *See* Langley, Samuel P.
- aerodynamics: in airplanes, 103–4, **105**, 110, 114, **115**, 116, 119, **122**, 127–28, 208–9; in automobiles, **93**, 203, **204**; in bridges, 169, 172, 249n28. *See also* streamlining
- Airflow car. *See* Chrysler Airflow
- airplane. *See* aviation
- Alexanderson, Ernst, 135
- alkylation, 78. *See also* oil refining
- alternating current (A.C.), 11, 13, 14, **16**, 25–34. *See also* electric circuits; electric power; Steinmetz, Charles; Tesla, Nikola; Westinghouse, George
- alternators, **16**, 135
- American Chemical Society, 71
- American Telephone and Telegraph Company (AT&T), 33, 51, 54; and long-distance telephony, 51–53; and radio, 53, 141, 143; regulation of, 54. *See also* Bell Telephone Company
- Ammann, Othmar, 11, 160, 161; and campaign for George Washington Bridge, 161–63; and design of George Washington Bridge, **159**, 163–65, **166**, **167**, **168**, 169, 170–71; later bridges of, 169, 172–75, 249n28. *See also* George Washington Bridge
- Ampère, André-Marie, 14
- amplitude modulation (AM), 135–36, **137**. *See also* Fessenden, Reginald Aubrey; radio; radio transmission
- Anderson, John D. Jr., 127–28
- angle of attack, 103, **105**. *See also* aviation, principles of
- antenna coupler, **139**, 143. *See also* radio reception
- arc lighting, 14, 17, 19, **20**, 22, 224n7, 225n10. *See also* electric lighting
- Armstrong, Edwin Howard, 12, 143, 145, 152, 153–54; and frequency modulation (FM), 153; patent litigation of, 149–51, 153–54; and the regenerative circuit, 143, **144**, 147, 150; and the superheterodyne receiver, **144**, 145–46, 147, 151, 245n25. *See also* de Forest, Lee; Sarnoff, David
- Ardmore, Pennsylvania, thin-shell roof, 197
- assembly-line manufacturing. *See* Ford, Model T: manufacturing of,
- AT&T. *See* American Telephone and Telegraph Company (AT&T)
- audion. *See* de Forest, Lee; triode
- automobile (gasoline-powered), xv, 6, 78, 79; early cars, 65, 80, 82–83, 86–87; engine, four-stroke cycle in, 79, **81**; Ford Model T, 65, 79, 87–88, 89, **90**, **91**, 92, **93**, **94**, 95, 100; fuel needs of, 57, 65, 75; later innovations in, 83,

- automobile (gasoline-powered), (*cont.*)  
100–101, 201–3, **204**, 205; production of (U.S.), 79, 95, 203; streamlining of, 203, **204**, 205. *See also* Chrysler, Walter P.; Chrysler Corporation; Ford, Henry; Ford Model T; Ford Motor Company; General Motors Corporation; Sloan, Alfred P. Jr., *See also* electric cars; steam cars. *See also specifically listed individual cars.*
- aviation, xv, 103; Boeing, William, and, 209–10; Cayley, Sir George, and 103–4, 110; Douglas, Donald, and, 206–8, 210–13, 216; early attempts to fly, 104; formulas for, 104, 105, 113, 115; fuel needs of, 75; Langley, Samuel P., and, 106–7, 120, 124, 127–28; Lilienthal, Otto, and, 104, 106; principles of, 103–4, **105**, 108, 110; streamlining and, 199, **200**, 208–11; Wright, Orville and Wilbur, and, 108–14, **115**, 116–18, **119**, 120–21, **122**, 123–28; Wrights, innovations after, 124, 126, 207. *See also specifically listed individual airplanes*
- Baldwin, Matthias, 6
- Baldwin locomotives, 6, 7
- Bayonne Bridge, 169, 174–75
- Bear Valley Mutual Water Company, 181
- Bell, Alexander Graham, xvii, 8, 35, 38, 50; aviation research in later life, 124; courtship and marriage to Mabel Hubbard, 45; Gray, Elisha, rivalry with, 47–48, 49; hearing and sound, Bell's interest in, 36, 40; patents and patent litigation of, 45, 47–48, **49**, 50, 225n13, 229n17; Salem lecture of (1877), 46; and science, 43, 54; as teacher of the deaf, 36–37, 40; telegraph research of, 40, **41**, 42–43, **44**; telephone research of, 43, **44**, 45, 48, **49**, 229n18. *See also* Bell, Alexander Melville; Hubbard, Gardiner
- Bell, Alexander Melville, 35, 36, 37
- Bell Laboratories, 33
- Bell System. *See* American Telephone and Telegraph Company; Bell Telephone Company
- Bell Telephone Company, 45, 48, 50–51; and conflict with Western Union, 48, 50. *See also* American Telephone and Telegraph Company
- Benz, Karl, 80
- Big Bear Dam, 181, 184
- Big Creek Dams (Eastwood design), 181, 187
- Big Meadows Dam, 181–82, 185
- Billington, David P. Sr., 2, 253n39
- Billington, James H., 2
- Boeing, William Edward, 209–10
- Boeing Monomail, 209–10, 211
- Boeing 247, 210
- Borden, Bill, 253n39
- Boston University, 37
- brake horsepower, 88, 118, **122**, 236n15
- Breer, Carl, 201–2, 203
- Bréguet, Louis-Charles, 208
- bridges, xv, 8, 9, 10–11; aesthetics, 173–75; arch bridges, 156, **157**, 169; cable bridges, 156, **157**, 169, 172; deflection theory and, 165, **168**, 169, 249n26; early modern bridges, in iron and steel, 155–56; safety factors and traffic loads for, 164–65, **166**, **167**. *See also* George Washington Bridge; *see also other specifically listed individual bridges*
- Brook Hill Dairy Exhibit roof, 187
- Brooklyn Bridge, 156, 158, 173
- Bronx-Whitestone Bridge, 175
- Brush, Charles F., 17
- Buick, David, 98
- Burton, William M., 11, 57, 65, 66, 71, 78; patent, 69, 70, 232n22; and science, 71–72;

- thermal cracking research, 65–66, 68–69. *See also* Burton process; oil refining; thermal cracking; Standard Oil Company; Standard Oil of Indiana
- Burton process, 57; control-volume analysis, as example of, 71–72; development of, 65–69, 70, 72, 78; limitation of, as batch process, 72; stills in operation, 73
- camber (in airplane wings), 110, 112
- Campbell, George A., 52; and inductive loading, 52–53, 54, 56, 230n26; and wave filter, 53
- capacitance, 52; in Hertz experiment, 131–32, 243n4; in radio tuning, 138, 139. *See also* electric circuits
- Cape Canaveral, Vertical Assembly Building at, 198
- car. *See* automobile
- carbon telephone transmitter, 7, 48. *See also* Edison, Thomas Alva
- Cardozo, Benjamin, 151
- Carnegie, Andrew, 8, 57
- carrier wave, 135–36, 137. *See also* radio, reception
- catalytic cracking, 75–76, 77, 78, 233n34; fixed-bed, 78; moving-bed, 78
- Cayley, Sir George, 103–4, 110
- Central Pacific Railroad, 178
- Century of Progress World’s Fair (Chicago, 1933–34), 187
- Chanute, Octave, 108, 113, 118
- Chevrolet, Louis, 99
- Chrysler, Walter P., 201–2; and Chrysler Motors, 201–3; and Zeder-Skelton-Breer group, 201–2
- Chrysler Airflow, 199, 201, 205; aerodynamic design of, 203, 204, 205; commercial failure of, 205
- Chrysler Building, 217, 219
- Chrysler Corporation, 11–12, 201–3
- Chrysler Six, 202. *See also* Chrysler Corporation
- Cincinnati Bridge (now the John A. Roebling Bridge), 156
- circuits. *See* electric circuits
- Clermont, 5
- coal gas: in lighting, 13, 14, 58; in Otto engine, 6, 79, 81
- coherer, 132. *See also* radio reception
- Columbia Broadcasting System (CBS), 147
- Columbian Exposition (Chicago, 1893), 30
- concrete, 177. *See also* reinforced concrete
- control-volume analysis, 71–72
- Coolbaugh, John and Kenneth, 149
- Coolidge, William D., 33
- Corliss, George, 4
- Corliss engine, 4, 5
- Cornell, Ezra, 38, 228n6
- Couzens, James, 85–86
- Craigellachie Bridge, 156
- Curtiss, Glenn, 124, 126–27
- Daimler, Gottlieb, 80
- dams: arch, 178, 180; earth, 178, 180; “flat slab,” 178; gravity, 178, 180; multiple-arch, 178, 181–82, 183, 185–86. *See also* Eastwood, John; Freeman, John. *See also specifically listed individual dams*
- Davy, Sir Humphrey, 14
- deflection theory, 165, 168, 169, 248n23, 249n26. *See also* George Washington Bridge; Tacoma Narrows Bridge
- de Forest, Lee, 53, 138, 140, 143; patent conflicts of, with Armstrong, 150–51; —, with Fessenden, 140, 244n15; triode (audion), develop-

- de Forest, Lee, (*cont.*)  
    ment of, 138, 140, 141, **142**. *See also* radio reception; radio transmission
- Delaware River Bridge, 164
- design. *See* innovation
- De Soto car, 203. *See also* Chrysler Airflow; Chrysler Corporation
- Detroit Automobile Company, 84
- diode, 141, **142**. *See also* Fleming, J. A.
- direct current (D.C.), 11, 13, 14, **16**, 17, 25–26, 28, 29–30, 131; direct-current motor, 31. *See also* Edison, Thomas Alva; electric circuits; electric power
- Dischinger, Franz, 251n23
- Dodge, Horace, 202
- Dodge, John, 202
- Dom Pedro (emperor of Brazil), 4
- Douglas Aircraft Company, 208. *See also* Douglas, Donald Wills
- Douglas, Donald Wills, 205, 207; aircraft company of, 208; and DC-1, 210–12, 213; and DC-2, 212; and DC-3, 212–13, 216; and Douglas World Cruisers, 208, 209. *See also* Douglas DC-3; streamlining, airplanes
- Douglas DC-1 and DC-2, 212
- Douglas DC-3, 199, 206, 216; design of, 210–13, **214**; performance of, 213, **214**, **215**, 216
- Douglas Skysleeper Transport (DST). *See* Douglas DC-3
- Douglas World Cruisers, 208, 209
- drag, 92, **93**, 104, **105**, **115**, 199, **200**; on Chrysler Airflow, 203, **204**; on Douglas DC-3, **214**, **215**; on Ford Model T, 92, **93**; form drag, 199, **200**; friction drag, **200**; on airplanes, **105**, 114, **115**; on Wright Flyer, 114, **115**, 116, **119**; on Wright gliders, 111–12; on automobiles, 92, **93**, **204**. *See also* lift
- Drake, Edwin L., 58, 59, 61
- Dubbs, Carbon Petroleum, 72. *See also* oil refining
- Dubbs, Jesse, 72
- DuPont, Pierre S., 99
- Durant, William C., 98–99, 201
- Duryea, Charles, 80
- Duryea, Frank, 80, 84
- Dyckerhoff & Widmann, 186, 251–52n23
- dynamo, **16**, 17. *See also* Edison, Thomas Alva, dynamo of
- Eads, James B., 156
- Eastwood, John, 11, 175, 176–78, 179; Big Bear Dam, 181; conflict with Freeman, 185, 186; Hume Lake Dam, 181, 182, **183**; later dams, 185–86; Mountain Dell Dam, 185, 251n17; multiple-arch designs of, 181–82; safety record of, 186
- Edgar, Graham, 74–75
- Edison, Theodore, 206–7
- Edison, Thomas Alva, 6–7, 8, 11, 13, 18, 84, 135, 206; and alternating current, 30; carbon telephone transmitter of, 7, 48, **49**; dynamo of, 23, **24**, 25, 220–22; and “Edison effect,” 140–41; engineering approach of, 34; incandescent electric light research of, 17, 19, **20**, **21**, 22; incandescent light bulb (1879), 22, 23; Joule’s Law, use of, 19; Ohm’s Law, use of, 17, 19, **21**; parallel circuit of, 17, 19, **20**; Pearl Street power plant and network, 25; phonograph of, 7, 17; power transmission, difficulties of, 22, 25–26, 29–30; and science, xvii, 19, 34, 220–22; telegraph inventions of, 7–8, 17, 40. *See also* Edison General Electric Company; electric lighting; electric power; Westinghouse, George; Westinghouse Electric Company

- “Edison Effect,” 140–41
- Edison General Electric Company, 25, 30. *See* General Electric Company; Westinghouse Company
- Edwards, Nelson, 197
- Eiffel, Gustave, 128, 156
- electric cars, 82, 83
- electric circuits, xix, 14, 15; alternating current (A.C.), 11, 13, 14, 16, 25–28, 29, 29–31, 131, 226n21; in automobiles, 90; capacitance and inductance, 52, 131–32, 138, 139, 243n4; direct current (D.C.), 11, 13, 14, 16, 17, 25, 28, 31, 131; parallel circuit, 17, 19, 20, 22, 220–22; in radio, 129, 130, 131, 132, 139, 142, 143, 144; resistance, 14, 15, 19, 21, 22; resonance, 138, 139; series circuit, 17, 20; in telegraphy, 37–38, 39, 41; in telephony, 43, 48, 49; in transformers, 28–29. *See also* electric lighting; electric power; electromagnetism
- electric lighting, xv, 6, 13, 14; arc lighting, 14, 17, 20; incandescent lighting, 14, 17, 19, 20, 22, 24, 25, 30; high-resistance filament in, 19, 21, 22; high-vacuum bulb in, 22; later improvements to, 33. *See also* arc lighting; Edison, Thomas Alva; incandescent lighting; Swan, Sir Joseph; Westinghouse, George
- electric power, xv, 13; alternators, 16, 135; dynamos, 16, 17, 23, 24, 25; generation of, 14, 16, 17, 24, 25; Edison (direct-current) system, 23, 24, 25–26, 29–30; transformers and, 28, 29; Westinghouse (alternating-current) system, 25–30.
- electric (electric-arc) welding, 72
- electromagnetism, 14, 15; in generating electricity, 14, 16, 17, 28; Henry and, 37, 39; in telegraphy, 37–38, 39, 40, 41; in telephony, 43, 48, 49, 52–53; in radio waves, 129, 130, 131–32
- engine. *See* internal-combustion engine; steam engine
- engine knock, 73
- engineering: as design, xvii; as four great ideas (structures, machines, networks, processes), xvi, 8–10; as narrative of great works, xviii; as normal and radical design, xvii. *See also* innovation; science
- English Visible Speech* (Bell), 36
- Ethyl Corporation, 74
- Euler, Leonhard, 127
- Evans, Harold, xvi
- ExxonMobil, xv. *See* Standard Oil of New Jersey
- Faraday, Michael, 14, 131
- Farquharson, F. B., 249n27
- Federal Communications Commission, 148
- Federal Radio Commission, 148
- Federal Trade Commission, 149
- Fessenden, Reginald Aubrey, 135, 136, 138, 143; and amplitude modulation (AM), 136; and broadcasting, 136, 147; and carrier wave, recognition of need for, 135; and heterodyning, 145–46; and high-frequency alternator, 135; patent conflict with de Forest, 140, 244n15
- filament. *See* electric lighting
- Finsterwalder, Ulrich, 251n23
- first law of thermodynamics, 68
- Fleming, John Ambrose, 140–41, 142
- Flügge, Wilhelm, 251n23
- Ford, Henry, 11, 65, 79, 83, 85; and aviation, 208; early companies and car models, 84–87; and Ford Model T, 87–88, 92, 95; and labor, 95, 96–97, 236n21; and moving assembly line, 92, 95; “quadricycle” and racecars, 84; rigidity and anti-Semitism in later years, 11–12, 100; rivalry

- Ford, Henry, (*cont.*)  
with General Motors, 98, 100; Selden patent, opposition to, 95–96; Taylorism, Ford methods opposed to, 101; Wright brothers, opposition to, 126. *See also* Ford Model T; Ford Motor Company
- Ford Foundation, 100
- Ford Lincoln Zephyr car, 205, 206
- Ford Model T, 6, 11, 65, 87; affordable cars, Ford's vision of, 86–87; basic design of, 87–88, 89; chassis, 89, 95; fuel system, 88, 90; engine, 10, 88, 91; horsepower, 88, 91, 92, 93, 235n14, 236n15; ignition, 88, 90; manufacturing of, 72, 92, 95, 97, 101; production and sales of, 95; transmission, 88, 92, 94; speed, 88, 94, 201; termination of, 100
- Ford Motor Company, xv, 84–87; and dealership system, 85–86; early cars of, 86–87; Ford Model T car, 87–95; labor relations in, 95, 96–97, 236n21; Lincoln Zephyr car, 205, 206; moving assembly line in, 92, 95, 97, 101; production and sales of, 86–87, 95, 98, 100, 236n19; in rivalry with General Motors, 100; static assembly in, 92, 96, 101. *See also* Ford, Henry; Ford Model T; General Motors Corporation
- Ford Trimotor airplane, 208
- form: in airplane design, 103, 105, 110, 208–9, 211; in automobile design, 203, 204, 205; in bridge design, 172–75, 177–78, 249n28; in dam design, 178, 180, 181; in roof design, 186–90, 197–98; in reinforced concrete, 176. *See also* mass vs. form
- formulas: simplicity of, xvii–xviii; use of, in book, 10–11
- Fortune 500 (2004), xv
- Frasch, Herman, 63–64, 71; Frasch process, 63–65, 71
- frequency modulation (FM), 136, 137, 153
- Freeman, John R., 185, 186
- Frye, Jack, 210
- Fulton, Robert, 5, 84; 1909 Fulton Centennial, 124
- Futurama Ride. *See* General Motors Futurama Ride
- Garabit Viaduct, 156
- gas lighting, 13–14, 25, 30, 58
- gasoline, 6, 11, 57, 58, 65; from catalytic cracking, 75–76, 77, 78; from distillation (simple), 58, 60, 65; from thermal cracking, 65–69, 70, 71–73; lead added to, 73–74, 101, 233n28; octane rating of, 74–75, 76, 233n33; production (U.S.) of, 72. *See also* oil refining
- Gaulard and Gibbs, 226n20
- Geddes, Norman Bel, 1, 3
- General Electric Company (GE), xv, 30–31; and radio, 135, 146, 149, 153; research laboratory of, 33; and Steinmetz, Charles, 31–33. *See also* Edison, Thomas Alva; Edison General Electric Company
- General Motors Corporation (GM), xv, 11–12, 79, 97, 201; and air-cooled engine, 101–2, 237n27; divisions of, 100; Durant, Will, founding by, 98–99; and leaded gasoline, 102; Sloan, Alfred P. Jr., reorganization and management by, 99–101. *See also* Sloan, Alfred P. Jr.
- General Motors Futurama ride, 1, 3. *See also* New York World's Fair (1939)
- generators. *See* electric power, alternators; electric power, dynamos
- George Washington Bridge, 8, 11, 12, 155, 174, 176; aesthetics of, 173–75; costs of, 159, 162,

- 169, 173; deflection theory, influence on design of, 165, 168, 169; design of, 159, 163–65, 166, 167, 169, 170, 171, 173–74; need for, 158, 160–61; public campaign for, by Ammann, 162–63; steel calculations for, 165, 167; traffic load estimate for, 164–65, 166, 173. *See also* Ammann, Othmar
- Gibbs, Josiah Willard, 138; Josiah Willard Gibbs Medal, 71
- Gibson, James, 188
- GM. *See* General Motors Corporation (GM)
- Golden Gate Bridge, 176, 186
- Gould, Jay, 50
- Gramme, Zénobe Théophile, 17
- Grant, Ulysses S., 4
- Gray, Elisha, 47, 54; patent conflict with Bell, 47–48, 50, 229n17; telephone of, 47–48, 49. *See also* Bell, Alexander Graham; Western Union
- “Great Aerodrome” (of Langley), 120, 124
- Great Western Power Company, 181
- Grove, Sir William, 14
- Harris, King and Lawrence, 55
- Harlem Board of Commerce, 163
- harmonic telegraph: Bell’s, 40, 41, 42–43; Gray’s, 47. *See also* Bell, Alexander Graham, telegraph research of; Gray, Elisha
- Harvard University, 37
- Hayden Planetarium, 187–88, 189
- Heaviside, Oliver, 53
- Hell Gate Bridge, 158, 160, 161
- Helmholtz, Hermann von, 36
- Henry, Joseph, 131; and Bell, Alexander Graham, 43; and electromagnetic telegraph, 37, 39. *See also* electromagnetism
- Hershey, Milton, 188–89
- Hershey Arena, 188–90; construction of, 190–91, 193–96; costs of, 252n31; design of, 190; labor, Hershey chocolate workers used for, 189–90, 193; forces and stresses in, 191, 192, 253n33. *See also* Tedesko, Anton
- Hertz, Heinrich, 129, 130, 131–32, 154
- heterodyning (in radio), 144, 145–46, 245n25. *See also* Armstrong, Edwin Howard; Fessenden, Reginald Aubrey
- Hibbing, Minnesota, thin-shell domes, 197
- Higgs, Paget, 220–22
- Holland, Clifford, 160
- Holland Tunnel, 160
- Hong, Sungook, 243n6
- Hooper, Stanford, 146
- horizontal force (in structure), 10–11, 156, 157; in George Washington Bridge, 167, 250n31; in Hershey Arena, 191, 253n33
- horsepower (hp), 10–11, 88, 92, 120; in Chrysler Airflow, 204; in Douglas DC-3, 214, 215; in Ford Model T, 88, 91, 92, 93; formulas for: brake hp, 88, 92, 236n15; —: indicated hp, 10, 11, 88, 91, 235n14; —: thrust hp (airplanes), 117–18, 119, 122, 214, 215; —: traction hp (cars), 92, 93, 204, 236n16; in Wright Flyer, 117–18, 119, 122, 215
- Houdry, Eugene, 57, 72, 75–76, 78
- Houdry process, 75–76, 77, 78. *See also* Houdry, Eugene; oil refining
- Hubbard, Gardiner, 40, 42, 45, 50
- Hubbard, Mabel, 40, 42, 45, 50; marriage to Alexander Graham Bell, 45
- Huber, Walter, 186
- Hudson, Henry, 124
- Hume Lake Dam, 181, 182, 183

—  
Index  
—

- Humphreys, Robert E., 65, 67; Burton process and, 65–66, 68–69, 71
- Huntington, Henry, 178, 181
- hydrocarbons. *See* oil, chemistry of
- incandescent (electric) lighting, 7, 14; Edison and, 17–19, 22; Swan and, 22. *See also* electric lighting
- indicated horsepower, 10, 11, 88, 91, 235n14
- inductance, 52; in Hertz experiment, 131–32, 243n4; in inductive loading, 52–53, 230n26; in radio tuning, 138, 139. *See also* electric circuits
- innovation: as normal and radical design, xvii. *See also* innovations (normal); innovations (radical)
- innovations (normal): in automobile design, 100–1; —, in aviation, 126, 207; —, in electric power and light, 32–33; in oil refining, 72–73; —, in radio, 153; —, in telegraphy, xvii, 40, 41; —, in telephony, 48, 52–54
- innovations (radical): in automobile design, 87–89, 90, 91, 92, 93, 94, 95; in aviation, 108–14, 115, 116–18, 119, 120–21, 122, 123, 210–13, 214, 215, 216, 219; in bridge design, 155–56, 163–65, 166, 177–78; in electric power and light, 17–19, 20, 21, 22, 23, 24, 25–30; in oil refining, 65–69, 70, 71–72, 75–76, 77; in radio, 132–36, 137, 138, 139, 140–41, 142, 143, 144, 145–46; in reinforced concrete dam design, 181, 183; in reinforced concrete roof design, 186–91, 191, 192, 193–96; in telephony, xvii, 43, 44, 45, 48, 49, 54
- Innovators, The* (Billington), xv
- Institute of Radio Engineers, 146, 150
- internal-combustion engine, 81; air-cooled engine, 100–101, 237n27; in Douglas DC-3, 214; in Ford Model T, 88, 91; four-stroke cycle in, 79, 81; Otto engine, 6, 79–80, 81; in Wright Flyer, 117–18, 119, 122
- Internet, the, xix
- Inventing America* (Maier et al.), xvi
- iron, 155–56; in early modern bridges, 156. *See also* steel
- Jablochkoff, Paul, 17
- Jones, Sir Bennett Melvill, 208–9
- Josiah Willard Gibbs Medal. *See* Gibbs, Josiah Willard
- Joule, James, 19
- Joule’s Law, 19, 34
- “Jumbo” dynamo, 25
- Kalinka, John, 197
- kerosene: for lighting, 6, 14, 30, 58, 63, 65; refining of, 58, 60, 61, 64–65, 68
- Kettering, Charles F., 33; and electric self-starter, 83; and engine knock, 73
- Keystone Bridge Company, 8, 9
- Lake Hodges Dam, 185, 186
- Langley, Samuel P., 106; aviation research of, 106–7, 120, 127–28, 241n28; failure of “Great Aerodrome,” 120, 124, 241n29; Wright brothers and, 108, 240n20. *See also* aviation; Wright, Orville and Wilbur
- Langley Aeronautical Laboratory, 127
- Langmuir, Irving, 33
- Latimer, Lewis, 225n13
- Leland, Henry, 84
- Levassor, Emile, 80
- lift, 103–4, 105, 114, 115; in Wright gliders, 110–12; in Wright Flyer, 114, 115, 116, 119, 215; in Douglas DC-3, 214, 215. *See also* drag

- Lilienthal, Otto, 104, 106, 108, 114, 116, 127  
“Lima-Indiana” oil, 63–65. *See also* Frasch, Herman; Frasch process  
Lincoln Zephyr car, 205  
Lindenthal, Gustav, 158, 161; and design for Hudson River bridge, 158, 159, 160  
Littlerock Dam, 185, 251n17  
“liquid” telephone, of Bell, 48; of Gray, 48, 49.  
*See* Bell, Alexander Graham, telephone research; Gray, Elisha  
Lloyds of London, 134  
Lodge, Oliver, 133–34  
Lowell, Francis, 4  
  
magnetism. *See* electromagnetism  
Maillart, Robert, 177–78  
Malcomson, Alexander, 85, 86  
Manly, Charles, 107, 120, 241n28  
Marconi, Guglielmo, 132–35, 138, 147, 154  
Marconi Company, 140, 143; in the United States, 146, 147  
Martin, Glenn L., 207, 208  
mass vs. form, 176–78. *See also* form  
Massachusetts Institute of Technology, 37  
Maxim, Sir Hiram, 238n3  
Maxwell, James Clerk, 129, 131, 132, 230n25  
Maxwell Motors, 201–2. *See also* Chrysler Corporation  
Mayer, Julius M., 150  
Menai Straits Bridge, 156, 173  
Menlo Park laboratory, 17, 18  
mercury vacuum pump, 22  
Midgley, Thomas, 73. *See also* gasoline  
Model T. *See* Ford Model T  
modulation: of amplitude, 136, 137; of frequency, 136, 137, 153  
  
Molke, Eric, 197  
Monomail airplane. *See* Boeing Monomail  
Moreell, Lieutenant-Commander Ben, 196  
Morgan, J. P., 8, 25, 57, 163  
Morrow, Dwight, 163  
Morse, Samuel F. B., 7, 37–38, 39  
Mountain Dell Dam, 185  
Murray, Sally, 197  
Museum of Modern Art (New York), 177  
  
Nally, Edward J., 146, 147  
National Advisory Committee on Aeronautics (NACA), 210–11  
National Broadcasting Company (NBC), 147  
Natchez, Mississippi, barrel-shell roof, 197–98  
Navier-Stokes equations, 127  
New York World’s Fair (1939), 1, 2, 3, 218, 219;  
General Motors Futurama ride, 1, 3; General Motors pavilion, 1, 3, 219  
Newcomen, Thomas, 4  
Newkirk, Jane, 82  
Noble, Alfred, 182  
normal innovation. *See* innovation; innovations (normal)  
Northrop, Jack, 211  
  
octane rating scale, 74–75  
Ohm, Georg, 14  
Ohm’s Law, 14, 15, 19, 21, 34, 48  
oil, chemistry of, 66, 68  
oil refining, xv; 6, 57; alkylation, 78; early history of, 58; catalytic cracking (Houdry process), 75–76, 77, 78; — (moving-bed processes), 78; distillation, simple (straight-run), 58, 60, 61, 65; Frasch process, 63–65; production (U.S.), 61, 64–65, 72, 74, 233n34; thermal cracking

- oil refining (*cont.*)  
(Burton batch process), 65–69, **70**, 71–72; —  
(Dubbs continuous process), 72–73; reforming,  
78
- Oldfield, Barney, 84, 86
- Olds, Ransom, 98
- Orsted, Hans Christian, 14
- Orsdel, Josiah van, 150
- Otto, Niklaus, 6, 79–80
- Otto engine, 79–80; and four-stroke cycle, **81**
- Packard Eight, **204**
- Paley, William S., 147
- parallel circuit, 17, 19, **20**, 22, 220–22. *See also*  
Edison, Thomas Alva; electric circuits
- Passer, Harold, 220
- Patent Office. *See* U.S. Patent Office
- patents: and airplanes, 123, 126; and automobiles,  
95–96; and oil refining, 69, **70**, 73; and radio,  
133, 138, 140, 141, 147, 148–49, 149–51, 153;  
and telegraphy, 38, 40; and telephony, 45, 47,  
48, 50, 53. *See also* U.S. Patent Office
- Pearl Street station, 25, 26
- Pennsylvania Railroad, 6, 8, 27, 158
- Perisphere, 218, 219. *See also* New York World’s  
Fair (1939)
- petroleum. *See* oil, chemistry of; oil refining
- Philadelphia Centennial Exhibition (1876), 4–8,  
9
- Philadelphia Skating Club and Humane Society,  
197
- phonograph, 7, 17. *See* Edison, Thomas Alva
- PLAN formula. *See* horsepower, indicated
- Plymouth car, 203. *See also* Chrysler Corporation
- Port of New York Authority, 162, 163
- Portland Cement, 177
- Prandtl, Ludwig, 128
- Progress in Flying Machines* (Chanute), 108
- Pupin, Michael, 53, 143
- radical innovation. *See* innovation; innovations  
(radical)
- radio, xv, 53, 129; Armstrong and, 143, **144**,  
145–46; de Forest and, 138, 140–41, **142**; Fes-  
senden and, 135–36, 138, 140, 145–46, 147;  
Fleming and, 140–41, **142**; Hertz’s experiments  
in, 129, **130**, 131–32, 243n4; Marconi and,  
132–35; Maxwell’s theory and, 129, 131–32;  
patent disputes in, 149–151, 153–54; popularity  
and public regulation of, 147–49; RCA and,  
146–51, 153–54; regenerative circuit in, 143,  
**144**, 146; Sarnoff and, 146–47, 148, 149–151,  
153; superheterodyne receiver in, **144**, 145–46;  
television and, 153–54; wireless telegraphy,  
132–35. *See also* amplitude modulation; Arm-  
strong, Edwin Howard; de Forest, Lee; electro-  
magnetism; Fessenden, Reginald Aubrey;  
Fleming, John A.; frequency modulation;  
Hertz, Heinrich; radio reception; radio trans-  
mission; Sarnoff, David.
- radio reception, 132, 138, **139**; rectifiers (detec-  
tors), early, 135–36; regenerative circuit, 143,  
**144**, 244n21; superheterodyne receiver, **144**,  
145–46, 245n25; triode as amplifier, 138,  
140–41, **142**
- radio transmission, 132, 135–36, **137**; amplitude  
modulation (AM), 135–36; broadcasting, 136,  
147; frequency modulation (FM), 136, **137**,  
153; high-frequency alternators, early use in,  
135; triodes, later use in, 147; wireless telegra-  
phy, 132–35
- Radio Act (1927), 148

- Radio Corporation of America (RCA), 146–49;  
Sarnoff and, 146–51, 153, and patent conflicts  
with E. H. Armstrong, 149–51, 153–54  
radio frequency spectrum, 133  
railroads, 5–6, 61, 156, 158; external-combustion  
engines used with, 6, 81  
reactances. *See* electric circuits  
refining of oil. *See* oil refining  
reforming. *See* oil refining  
regenerative circuit, 143, 144, 244n21  
reinforced concrete, xv, 175, 176; in dams,  
181–82, 183, 184–86; mass versus form in,  
177–78; in thin shells, 186–191, 191, 192,  
193–98  
Reis, Philip, 43  
resonance (in radio), 138, 139; in Hertz experi-  
ments, 131–32  
Righi, Augusto, 132  
Ritter, Wilhelm, 160  
Roberts and Schaefer Company, 187, 188, 197  
Rockefeller, John D., 6, 57, 62; consolidation of  
refining industry by, 61, 63; controversy about,  
63; innovation and, 64  
Rockne, Knute, 210  
Roebbling, John A., 156, 173  
Rogers, F. M., 65  
rolling resistance, 92, 93  
Roosevelt, Eleanor, 196  
Roosevelt, Franklin, 196  
Roosevelt, Theodore, 63  
Rüsch, Hubert, 251n23  
  
St. Francis Dam, 186  
Salginatobel Bridge, 178  
San Joaquin Electric Company, 178  
Sanders, George, 37  
Sanders, Thomas, 37, 42, 45  
Sarnoff, David, 146–47, 148, 151; broadcasting,  
vision of, 147; conflicts with Armstrong,  
149–51, 153–54; television and, 153  
Schuyler, James D., 182  
Schwertner, Charles, 197, 253n39  
science: as discovery, xvii; and engineering educa-  
tion, xviii; contributions following radical inno-  
vation, 32–33, 52–53, 54–55, 128, 208–9; ef-  
forts to model engineering as, xviii, 32–33, 101,  
173; lack of stimulus to radical innovation, 34,  
78, 127–28, 220–22; radio as applied science,  
154, 243n6  
“scientific management,” 101. *See* Taylor,  
Frederick W.  
*Scientific American*, 124  
Selden, George, 95–96, 126  
Sherman Antitrust Act (1890), 63, 149  
Silliman, Benjamin Jr., 58  
Silzer, George, 162, 163  
Sinclair, H. H., 182, 185  
Skelton, Owen, 201  
Sloan, Alfred P. Jr., 79, 97; General Motors, reor-  
ganization by, 99–100; innovation, cautious ap-  
proach to, 100–101  
Smeaton, John, 114; Smeaton coefficient, 114,  
115, 116, 240n20  
Smith, Al, 163  
Smithsonian Institution, 106, 108; Henry’s advice  
to Bell, 43; Langley’s aviation research, 106–7,  
120; dispute with Wright brothers, 11, 127  
Standard Oil Company, 6, 57; breakup (1911),  
63, 64; consolidation of, 61; early innovation  
in, 63–65; opposition to Burton process, 11, 69;  
reorganizations of, 63, 69, 232n11. *See also*  
Standard Oil of Indiana

- Standard Oil of Indiana (later Amoco, now BP America), 65, 69, 72; and support for Burton process, 69
- Standard Oil of New Jersey (later Exxon, now ExxonMobil), 63, 72, 76
- Stanley, William, 28
- Stanley steamers. *See* steam cars
- Statue of Liberty, 125
- steam cars, 82–83
- steam engine, xix, 4–6; Corliss engine, 4; and dynamos, 17, 25; Newcomen engine, 4; in railway locomotives, 5–6, 79; in steamboats, 5; in steam-powered automobiles, 82; Watt engine, 4, 11
- steel, 8, 57; in bridges, 155, 156; in the Ford Model T, 87–88; in George Washington Bridge, stress calculations for, 165, 167. *See also* iron; Ammann, Othmar; George Washington Bridge
- Steinmetz, Charles, 31–32, 227n30; contributions to alternating-current engineering, 31–33
- Stephenson, George and Robert, 5–6
- streamlining, 199, 200; of airplanes, 208–9; of automobiles, 201; in Chrysler Airflow, 203, 204, 205; in Douglas DC-3, 210–13, 214, 215, 216, 219; metaphor of American society in 1930s, 219; metaphor of engineering, 219. *See also* Chrysler Airflow; Douglas DC-3
- Studebaker Corporation, 201
- Sturgeon, William, 14
- Sun Oil Company (Sunoco), 76
- superheterodyne receiver, 144, 145–46, 147, 151, 245n25
- Swan, Sir Joseph, 22
- Tacoma Narrows Bridge, 12; collapse of, 169, 172, 186
- Tarbell, Ida, 63
- Tate, Bill, 111
- Taylor, Frederick Winslow, 101
- technology. *See* engineering
- Tedesko, Anton, 175, 176–77, 186–87, 188, 196; Brook Hill Dairy Exhibit roof, 187; Hayden Planetarium dome, 187–88, 189; Hershey Arena roof, 188–91, 195–96; shells after Hershey Arena, 197–98; Z-D Shell Roofs and, 186–87. *See also* Hershey Arena
- Telefunken (now AEG Telefunken), 143
- telegraph, 7–8, 35, 37–38, 39; Bell’s harmonic telegraph, 35, 40, 41, 42–43; Edison’s quadruplex and other inventions, 7, 17, 40; Henry’s electromagnetic telegraph, 37, 39; Marconi and wireless (radio), 132–35; Morse and, 7–8, 37–38, 39; Stearns duplex, xvii, 40. *See also* Cornell, Ezra; Western Union; radio
- telephone, xv; business and social uses of, 54; development of, by Bell, 8, 35–36, 40, 41, 42–43, 44, 45, 46, 47–48, 49, 229n18; Edison’s carbon transmitter, 49; exchanges and operators, 51, 52; Gray’s telephone, 47–48, 49; inductive loading, 51–53; long-distance calling, 48, 50, 51–53, 54; patents for, 45, 47–48, 50, 51, 53; Reis telephone, 43, 48; triode, use to amplify long-distance calls, 53, 141. *See also* Bell, Alexander Graham; Gray, Elisha; Campbell, George A.
- television, 153, 154
- Telford, Thomas, 11, 156, 173
- Tesla, Nikola, 31, 32, 140
- tetraethyl lead (gasoline additive), 73–74, 101
- Texas Company (Texaco), 72
- thermal cracking: Burton (batch) process, 65–69, 70, 71–72; Dubbs (continuous) process, 72–73;

- octane ratings of thermally-cracked gasoline, 74–75, 76
- They Made America* (Evans), xvi
- thin shells, 176; Brook Hill Dairy Exhibit roof, 187; Hayden Planetarium, 187–88, 189; Hershey Arena, 186–191, 191, 192, 193–96; later Tedesko shells, 197–98. *See also* Tedesko, Anton
- Thomson, J. Edgar, 6
- Thomson-Houston Company, 30
- Throgs Neck Bridge, 175
- thrust horsepower, 117–18, 119, 122
- thrust, 104, 105, 117–18, 119, 122. *See also* horsepower; formulas
- Tjaarda, John, 205
- traction horsepower, 88, 92, 93, 204
- traction force, 93, 204
- Transcontinental and Western Airlines (TWA), 210
- transformers, 28; in electric power transmission, 28–29, 29, 30; magnetic loss in, 31–32; *See also* electric power
- traffic load estimates: Ammann’s, 164–65, 166, 173; Waddell’s, 164. *See* Ammann, Othmar; George Washington Bridge; Waddell, J.A.L.
- triode (audion), 53, 138, 140–41, 142, 147, 150. *See also* de Forest, Lee; radio reception; radio transmission
- Trylon, 218, 219. *See also* New York World’s Fair (1939)
- United States International Exhibition. *See* Philadelphia Centennial Exhibition
- United States Steel, 8, 57
- U.S. Army, 124, 143, 208
- U.S. Army Corps of Engineers, 163–64
- U.S. Army Signal Corps, 207
- U.S. Circuit Court (District of Columbia), 150
- U.S. Congress, 208, 210
- U.S. Court of Appeals (New York), 150
- U.S. District Court (Southern District of New York), 150
- U.S. Navy, 146, 206, 208
- U.S. Naval Academy, 206
- U.S. Patent Office, 45, 150
- U.S. Post Office, 50, 208
- U.S. Supreme Court, 63, 151
- U.S. War Department, 107
- vacuum bulbs. *See* electric lighting
- vacuum tubes. *See* diode; triode
- Vacuum Oil Company, 75–76
- Vail, Alfred, 50
- Vail, Theodore N., 50–51, 54
- Verrazano Narrows Bridge, 172, 175
- vertical force (in structure), 156, 157; in George Washington Bridge, 167
- Vincenti, Walter, xvii, 71
- “visible speech,” 35–36. *See* Bell, Alexander Melville
- Volta, Alessandro, 14
- Waddell, J.A.L., 163, 164
- Walcott, Charles, 127
- Watson, Thomas A., 42, 43, 45, 53
- Watt, James, 4, 11, 88, 235n14
- watt (electric unit), 25, 225–26n15
- wave filter, 53
- Webber Creek Dam, 185
- Western Electric Company, 47, 50
- Western Society of Engineers, 114

—  
*Index*  
—

- Western Union, 7-8, 39, 40; acquisition and divestiture by AT&T, 54; patent dispute with Bell Telephone Company, 48, 50
- Westinghouse, George, 11, 13, 25-28; air brake of, 26-27; alternating current, use of, 28-30, 226-27n22
- Westinghouse Electric Company, 28; Edison General Electric, rivalry with, 30; and radio, 147, 149; research laboratory, 33
- whale oil, 58
- Whiting laboratory, 65, 67
- Williams, Charles, 42
- Wills, C. Harold, 85
- Willys-Overland, 201
- Winton, Alexander, 84, 95
- World Cruisers. *See* Douglas World Cruisers
- World's Fairs. *See* Philadelphia Centennial Exhibition (1876); New York World's Fair (1939-40)
- Wright, Orville and Wilbur, 11, 12, 103, 109; basic ideas of, 108, 110; design of 1903 Flyer, 116-18, 119, 240n26; first powered flight (1903), 120-21, 122, 123; gliding research, 110-14, 116, 117, 239n14; kite experiment, 110; later flights of, 123, 124-25, 205; patent (1906), 123, 126; and Smithsonian Institution, 108, 127; and theoretical aerodynamics, 127-28; wind tunnel tests, 114, 115, 116, 240n18. *See also* Wright Flyer
- Wright Flyer (1903), 103, 123, 127; comparison to Douglas DC-3, 213, 215, 216; design of, 114, 115, 116-18, 119, 240n26, 241n28; engine of, 117-18, 119, 122, 240n24; performance of, 120-21, 122, 123, 241n31; propeller difficulties of, 118, 120, 240n26
- Wright gliders and kite, 114; 1899 kite, 110; 1900 glider, 110-12, 239n14; 1901 glider, 112-13; 1902 glider, 116, 117
- Young, Owen D., 146, 147
- Zahm, Albert, 127
- Z-D (Zeiss-Dywidag) Shell Roofs, 187
- Zeder, Fred, 201
- Zeiss Optical Company, 251-52n23