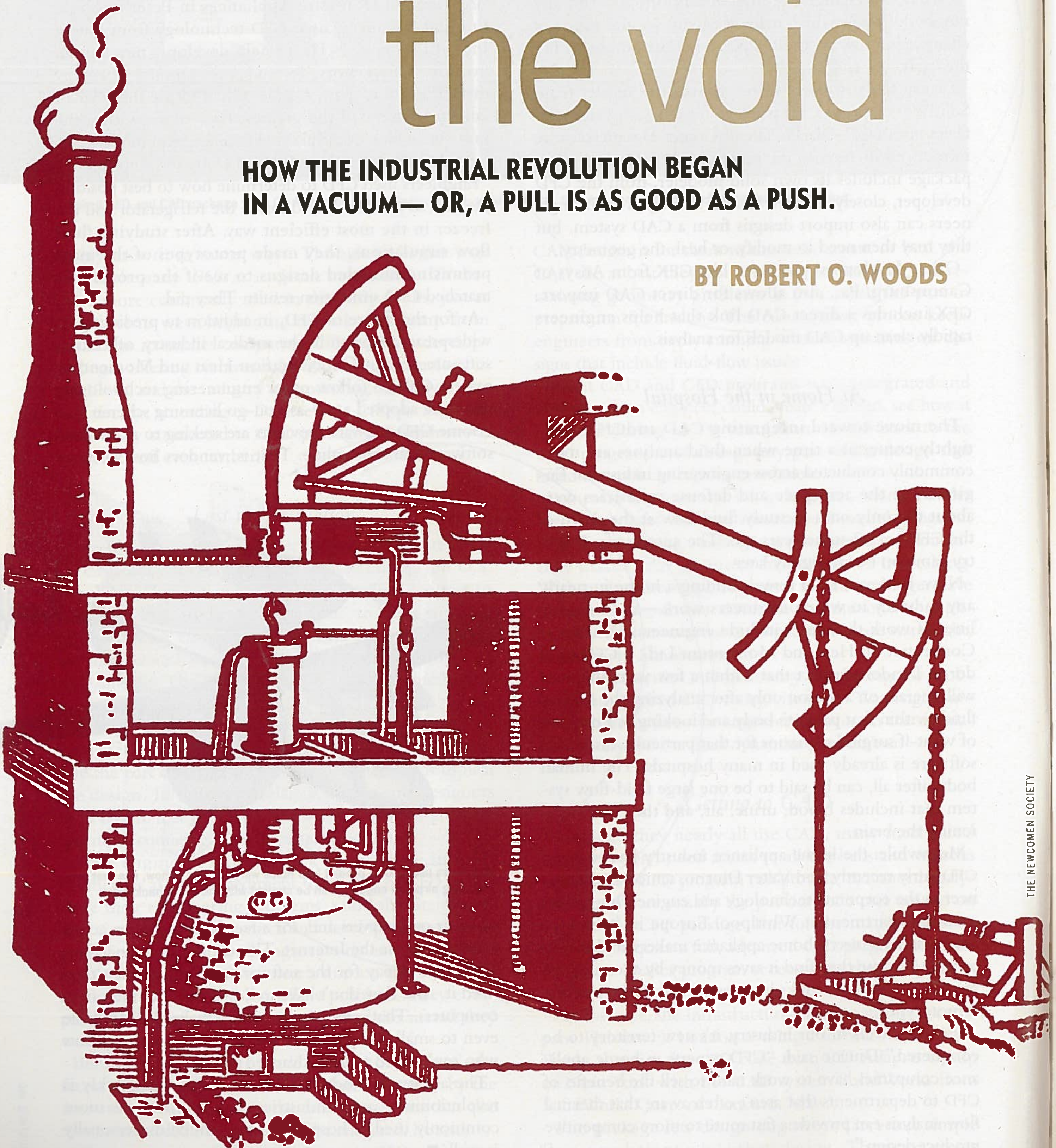
Harnessing the void

HOW THE INDUSTRIAL REVOLUTION BEGAN IN A VACUUM— OR, A PULL IS AS GOOD AS A PUSH.

BY ROBERT O. WOODS



THE NEWCOMEN SOCIETY

It frequently happens that the individual getting the credit for an invention is not the real innovator, but rather the person who was most successful in reducing an idea to practice. Thus, we never hear about the designers of sailing ships who had made an extensive study of aerodynamics before the Wright brothers, or the number of engineers who had speculated on jet propulsion before Whittle.

This is true of steam power. The conventional wisdom is that James Watt invented the steam engine. The contribution of Thomas Newcomen, who died a few years before Watt was born, is usually overlooked.

The extent to which Watt's reputation has eclipsed Newcomen's can be judged by comparing their entries in the *Britannica*. The encyclopedia gives Watt nearly two pages, while Newcomen rates only a brief paragraph. Nonetheless, it was Newcomen who first made the steam engine a reality.

Man's fascination with the fact that water can be converted to a vapor by the application of heat probably dates to prehistoric times. The first documented effort to exploit this phenomenon to create mechanical motion is generally credited to Hero of Alexandria, who invented his aeolipile in the first century. His contrivance is always cited as the first example of jet propulsion. Hero's pinwheel was no doubt great fun to watch if you had never seen anything but chariot wheels, but it went nowhere.

Galileo and Other Great Names

The first practical steam engine did not materialize until the 1700s, and it did not appear as a finished product. Its evolution can be traced in a line that started in the 1640s and involved a number of great names, beginning with Galileo.

The key to steam power was forged when it became understood that air exerts pressure. This came as a revelation to post-Renaissance scientists. Earlier generations had been enslaved by a blind adherence to the teachings of Aristotle, who saddled nearly 2,000 years' worth of philosophers with the information that "nature abhors a vacuum," and that was really all they needed to know about it.

Evangelista Torricelli showed that the "abhorrence" of a vacuum was entirely understandable and not due to the whim of a mysterious entity called Nature. Torricelli had undertaken his investigations at the suggestion of his mentor, Galileo, who was puzzled because water could not be siphoned beyond 32 feet. Galileo concluded that Nature abhorred a vacuum, but it probably didn't abhor it all *that* much.

Torricelli, with one of the flashes of intuition that advance science at a single leap, concluded in 1643 that air must have weight. Torricelli's hypothesis was investigated by Blaise Pascal in 1647, who conducted mountain climbing experiments to study the ramifications of the discovery. Pascal reasoned that if air has weight, pressure must decrease with altitude, and performed experiments with mercury barometers to prove it.

At the same time, Otto von Guericke was independently conducting his famous demonstrations known as the "Magdeburg spheres." He explored the capabilities of small vacuum pumps, hardly bigger than present-day syringes, to evacuate vessels and make it virtually impossible to remove the lids. In one famous episode in 1654, he fabricated a vessel of two hollow hemispheres, evacuated it, and demonstrated that 50 men in unison were unable to pull it open.

Now that atmospheric pressure was a phenomenon subject to analysis, the scene was set for its numerical formulation. Robert Boyle did so and the product is the law that bears his name. Boyle worked with Robert Hooke, who is equally well known, and it was their protégé, Michael Papin, who first attempted to put atmospheric pressure to work.

In the 1690s, Papin tried to perform useful work by evacuating cylinders and allowing atmospheric pressure to drive a piston. His experiments did not result in any practical application, perhaps because he was using, among other things, gunpowder explosions to drive some of the air and combustion products from a cylinder and then trying to work with the partial vacuum created when the gases cooled.

A few years after Papin's work, in 1698, Thomas Savery did, in fact, put atmospheric pressure to work. He received a patent for the first commercially feasible application.

His invention did not involve moving parts. It was an exercise in creative plumbing. His work was motivated by the fact that some means of pumping the water from mines had become a life-or-death matter to the mining industry in Britain.

'The Miner's Friend'

Shallow mines were being exhausted and shafts had to be sunk to increasing depths where seepage became a proportionally greater problem, and water had to be pumped a greater distance. Savery's patent, called "The Miner's Friend," was for a water pump that functioned by admitting steam to a chamber, condensing it by cooling the *outside* of the chamber, allowing the partial vacuum to siphon water into the vessel, and then lifting the water with steam pressure.

This involved a lot of manipulating of valves. Savery used pressures of no more than 140 psi, which was the limit of technology at the time. Saturated steam above

The Newcomen steam engine provided power to lift water that seeped into ever-deepening mines in the Old World. Atmospheric pressure drove a piston into the partial vacuum left by condensing steam inside the cylinder.

Robert O. Woods, an ASME Fellow and a frequent contributor to* Mechanical Engineering *magazine, visited the Newcomen engine exhibit at the Science Museum in London. He said, "It is such a primitive and brutal-looking apparatus that it arouses a sort of morbid curiosity."

that pressure melted his soldered pipe joints.

Primitive as it was, the Savery pump was used for several decades and competed for a time with the Newcomen engine.

Thomas Newcomen (1663-1729) must be credited, by anyone who looks beyond Watt, for beginning the Industrial Revolution. He worked with an assistant named John Calley, who did most of the hardware work. Calley's name is another that has been overlooked by history—along with that of Newcomen's wife, Hannah, who appears to have run his business while he was experimenting with steam.

Newcomen's engine, like Savery's, was created to pump water from mines. Savery's patent covered any "vessells" for raising water or powering millworks "by the impellent force of fire." Remote as his invention was from Newcomen's, his patent proved impossible to circumvent. Newcomen and his partner Calley were forced to form a company involving Savery. Savery's triumph, however, was short-lived. He died within a year and his rights were acquired by his successors.

More Efficient Than Horses

The Newcomen engine was staggeringly inefficient by today's standards, but it was a commercial success for a time because it was the only practical alternative to pumps powered by horses.

Most important, it introduced the concept of mechanical engines. It was later pointed out that that was not an entirely unmixed blessing. Because of their inefficiency, Newcomen's engines burned vast quantities of coal, producing the pall that was characteristic of the Industrial Revolution in England and giving rise to what the poet William Blake would later call "dark satanic mills."

Relatively little is known about Newcomen's education. He described himself as an "ironmonger," which can probably be interpreted to mean hardware manufacturer. He is known to have provided metal items to the tin mines, which were going to progressively greater depths, and he certainly became aware of the need for pumping there.

Newcomen's first engine went into operation around 1710. It was more than 50 years later that James Watt introduced the steam engines of his contrivance. Watt's engine was not a fundamentally new concept, but it had the advantage over Newcomen's of greatly improved efficiency. Watt made the steam engine economically attractive and allowed its use in applications that the Newcomen engine was too wasteful to serve. Hence, Watt gets the credit.

Despite its appetite for coal, however, examples of the Newcomen engine were still in operation as late as the 1900s.

Both Watt's and Newcomen's engines in their first stages used a "walking beam" linkage, in which the linear motion of a piston was translated to another linear motion in a reciprocating pump. Both inventors understood that this arrangement limited applications almost exclusively to pumping.

Both explored the use of ratchet wheels to produce a more useful rotary motion. Watt would later create the now-familiar connecting rod and crankshaft, which were ultimately applied to both engines. Interestingly, when a smooth rotary motion was needed, a sort of crude fluid drive was invented by having the reciprocating pumps deliver water to a reservoir, which then served a water wheel.

The aspect of a typical Newcomen engine that is most eccentric from a modern point of view is that it didn't work using steam pressure at all. In the Newcomen cycle, steam was admitted to a cylinder and then condensed by injecting a water spray.

Newcomen's Innovation: Water Injection

This water injection was Newcomen's great innovation. It allowed faster cycle time and avoided the waste of the heat that would be lost in heating and then cooling the thermal mass of the chamber itself. Actual work was performed by atmospheric pressure, forcing the piston into the partial vacuum left by condensing steam. Later measurements found that the cycle produced a mean effective pressure of 9½ psi at best.

The cylinder, which might be as much as several feet in diameter, was usually located directly above the boiler for no particular reason except to reduce the length of piping between them. In later cases, more than one boiler was placed beside the cylinder, allowing uninterrupted operation while a boiler was being repaired.

A choice of boiler material permitted considerable latitude because the boilers operated at nearly zero gauge pressure. Thus, a whimsical assortment of copper and lead sheet with soldered joints was used in early models. Cylinders were initially made of brass. This was later replaced with cast iron.

The art of cylinder boring was in its infancy; thus, the fit of a piston and cylinder of large size was absurdly poor

Taking the Longer View

The author recommends the following books to readers interested in pursuing the story in more detail.

- *The Steam Engine of Thomas Newcomen*, by L.T.C. Rolt and J.S. Allen (Landmark Publishing, Britain, 1997).
- *A Short History of the Steam Engine*, by H.W. Dickinson (MacMillan, New York, 1939).
- *A History of the Growth of the Steam Engine*, by R.H. Thurston (Cornell University Press, Ithaca, N.Y., 1939).
- *Science as History*, by H. Gartmann (Hodder & Stoughton, London, 1960).

by our standards. The only existing boring machines were used to produce cannon. They machined a diameter of a few inches at most.

Larger cylinders had to be hand ground and lapped. This was obviously a very inaccurate operation. One inspector expressed great satisfaction when a piston fitted the cylinder with an error less than the width of his little finger. Poor fit was compensated for by using a wide annular leather packing, which was kept lubricated and supple by providing a constant trickle of water to the top of the piston. That's a feature some writers seem to regard as a significant innovation.

Fairbottom Bobs, a Newcomen steam engine recovered from a mine site in Lancashire, England, was acquired in 1930 by the Henry Ford Museum, which says it is possibly the oldest extant steam engine in the world.

Newcomen's boiler design was very naïve from a heat transfer standpoint. That heat transfer area should be made as large as possible had not occurred to anyone. Hence, boiler shape was generally very inefficient. Efficiency was not helped by Newcomen's belief that the volume of steam being produced was proportional to the volume of water in the boiler, rather than to the heat input.

Smeaton Pitches In

The first attempt at anything resembling a scientific investigation of the engine did not take place until the 1770s, when it was undertaken by an engineer who was the Vannevar Bush of his time: John Smeaton. Ninety-nine engines had been built by that time. Fifty-seven were in operation. The largest had a bore of 75 inches. Smeaton, more than anyone else, was responsible for promoting the use of the Newcomen engine.

By shrewdly choosing to make the right measurements, Smeaton found, for example, that an engine with a 52-inch-diameter piston and 7-foot stroke, running at 12 cycles ("vibrations") per minute and 7½ psi, developed 40 horsepower. Seven psi was later to become the nominal pressure used by designers.

After Smeaton introduced a few numbers into the discussion, a study was performed for the benefit of skeptics. The engines had been in operation for some time by then, and it was possible to demonstrate their financial advantage over horse-driven pumps. An engine with a cylinder diameter of 1 foot and a 5-foot stroke was seen to pump 250,560 gallons of water a day at a cost of 20 shillings. Two horses, working two-hour shifts, were able to pump 67,200 gallons in the same time at a slightly higher cost. Pump performance even allowed for six hours a day spent in routine maintenance.

One of Newcomen's greatest contributions was to develop mechanisms to perform his cycle automatically. Early versions of his engine involved manually manipulated valves. This was a slow operation and provided an opportunity for disastrous errors; it clearly indicated a need for mechanical actuators.

The earliest actuators were brute force machines, involving rods with adjustable pins, linked to the beam and impacting valve handles as they moved up and down. Later versions had fairly sophisticated linkages resembling clock escapements.

That a powerful machine could regulate itself was a startling innovation in the 1700s, when the only autonomous machines were clocks. A lot of folklore, almost certainly apocryphal, has arisen about the valve actuators.

The most popular fable arose when a writer was told that the valves were regulated by a buoy—which was the term for a float actuator. In some versions of the story, this was interpreted to mean that a "boy" was manipulating the valves and this misinformation has been immortalized. Tales are still told raising this (probably) nonexistent boy to the same status as Jack in the story about the beanstalk. He has even been given a name, Humphry Potter, and we are informed that he invented valve actuators by tying strings to the valves because he was too lazy to cycle them manually.

ASME declared the Newcomen engine an International Historic Mechanical Engineering Landmark in 1981. ■