To Power the World

How flooded mines provided a golden opportunity to harness the power of steam.

The Engineer

In 1712, Thomas Newcomen was a middle-aged man of forty-nine. Born into a landless noble family in Dartmouth England during the early months of 1664, Newcomen had worked his way to becoming a successful ironmonger in the Dartmouth area through a series of social connections he had made through his Baptist faith.[1] It would have been an exciting time to be a Baptist in England. In 1687 James II had suspended many of the penal laws that enforced conformity to the Anglican Church through the Declaration of Indulgence.[2] By 1704 the Conventicle law, which had prevented five or more people from separate households meeting at once, was beginning to be relaxed.[3] This marked the beginning of the end of the legal persecution of nonconforming Christian sects in England. Because Baptists were freer than ever to meet and mingle, Newcomen had met his wife Hannah at a Baptist meeting house. By 1712 they had been married for seven years and were busy building a family.[4] Aside from family and faith, there would have been one more thing occupying the mind of Thomas Newcomen. He had spent the last two decades working tirelessly on a new product that he hoped would solve his customers' biggest problem.[5] In 1712, it was ready.

[1] Corfield 213, 215
[2] Corfield 211
[3] Corfield 211, 215
[4] Corfield 213
[5] Corfield 215

At that time, ironmongers not only supplied tools, they also crafted them.[6] Newcomen and his business partner John Calley, a plumber and glazer by trade, were brought together by a shared community and faith.[7] They opened their business in Dartmouth sometime between 1685 and 1688. Newcomen and Calley would have had a workshop and employees to help manufacture goods of iron, brass, copper, tin, and lead.[8] As historian Brian Corfield notes, they would have been "thoughtful and highly practical craftsmen capable of understanding their customers' multifarious needs and then devising a solution to meet them." [9]

As an ironmonger, Thomas Newcomen visited and supplied tools to tin mines in Devon and Cornwall.[10] There, miners were having difficulty extracting deeper veins of tin, because the high water table kept flooding out the tunnels. In other areas, mines with flooding issues relied on animal or water wheel power to operate pumps and extract the floodwater.[11] Unfortunately, for those mines in Devon and Cornwall, the shafts were becoming too deep for animal power and there were no available rivers to run a waterwheel.[12] Seeing this need likely inspired the industrious Thomas Newcomen to embark on a decades long project.[13] He was going to build an atmospheric engine to pump the water for his customers.

The idea of using an atmospheric pump to drain mines was not a new one. In 1696, Thomas Savery took out a patent for "*Raising water by the impellent force of fire*". [14] Savery showed his invention to King William III at Hampton Court before later demonstrating that same

[6] Corfield 213
[7] Corfield 213-214
[8] Corfield 214
[9] Corfield 214
[10] Hills 22
[11] Hills 22
[12] Hills 22
[13] Hills 22 Corfield 215-16
[14] Hills 16

model before the Royal Society in 1699. [15] His demonstrations must have impressed their audiences, as he received enthusiastic support allowing him to construct larger prototypes at Campden House in Kensington and York Buildings in London.[16] Unfortunately, while his scale models may have been impressive, Savery's invention lost considerable efficiency when built at full size[17]

The way Savery's engine worked was by applying what was then recently understood principles about the weight of the atmosphere. In 1643, Galileo Galilei and Evangelista Torricelli demonstrated that it was impossible for a piston pump to draw water any higher than 28 feet into the air. They hypothesized that the weight of the atmosphere was unable to push water any higher up the tube than that point.[18] In 1672, Otto von Guericke, in Germany, demonstrated in an experiment that sixteen horses could not separate two hemispheres of a metal ball when all the air had been removed from inside.[19] Later, von Guericke pumped air out of a cylinder with a plate on top connected to a pulley with weights at the end. He found that removing the air from the cylinder drew the plate into the cylinder and caused the weight to lift. This demonstrated that atmospheric pressure could do actual work.[20] Having heard of the progress Europeans were making in the study of atmospheric pressure, in 1658 the Englishman Robert Boyle built the first prototype for what is, in essence, the modern air pump. Using this device, which he called a *vacua*, Boyle preformed a series of experiments that ultimately led him to formulate his law of the pressure of gas known today as "Boyle's Law".[21] Denis Papin was a Frenchman who assisted

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[15] Hill 16
[16] Hill 16
[17] Hill 16
[18] Hill 14-15
[19] Hill 15 Allen 158
[20] Allen 158
[21] Hill 15

Boyle in making vacuum chambers.[22] Papin was a former assistant of Christiaan Huygens who, in 1666, had been experimenting with exploding gunpowder to drive a piston up a cylinder to create a vacuum.[23] Upon reaching England and beginning his work with Boyle, Papin continued to experiment with gunpowder. He created vacuum chambers by using the explosive force of gunpowder to expel air out of a chamber through one-way valves.[24] He soon had a breakthrough when he realized that filling a chamber with steam and then rapidly condensing it to water served the same purpose.[25] At this point the fundamentals of the atmospheric steam engine had been discovered. What they needed was someone to bring those pieces together.

Thomas Savery was not that man. His atmospheric pump was not an engine, though it represents the first attempt at applying the principles of atmospheric pressure to a commercial purpose.[26] Savery's pump worked by first heating water to steam in a boiler. That boiler then fed steam into two lozenge-shaped receivers that were doused with water to condense the steam and create a vacuum. This vacuum would draw directly upon the floodwater, pulling it up and into the receivers. The next time the operator turned on the steam it would push the water out of the receivers, into a sluiceway, and out of the mine.[27] The problem with Savery's pump is that it was wildly inefficient. Every time the receivers were filled, steam would be needed to drain them. Additionally, the cold water would cool down the receiver chambers. This meant that any steam injected into them would condense too early. So, they would need to be heated up with additional steam before they got a final injection and dousing. This waste of steam meant a waste of fuel.[28]

[22] Hill 15-16
[23] Allen 158
[24] Hill 15
[25] Allen 158
[26] Allen 158
[27] Hill 17-18
[28] Hills 18

Additionally, the pump was manually operated and required a skilled, tireless worker to be operating every valve; monitoring the water and pressure levels; alternating, draining, and heating the receivers; and stoking the fire.[29] It is no wonder then that despite its initial enthusiastic reception, Savery's pump never saw the success of Newcomen's engine.[30]

In 1712, Thomas Newcomen's first engine was ready. It was constructed near Dudley Castle in Staffordshire and had incorporated or improved upon all that had come before.[31] It had Huygens's cylinder and piston, though like Papin it used steam rather than gunpowder to create a vacuum.[32] Like Savery, the engine had a separate external boiler and would be used to drain mines. However, unlike Huygens's design, Newcomen hung the piston from a beam that was attached to an offset pivot. The other end of the beam connected to a bucket pump in such a way that the weight of the pump held the piston up and in an open position between cycles.[33] This configuration meant that the vacuum created by condensing steam drew the piston down, in turn pulling up on the bucket and drawing water to the surface. Newcomen added to this the accidental discovery of cold-water injection. Newcomen's close associate, the Swedish engineer Marten Triewald, wrote in his book that as Newcomen was experimenting with models for his engine, a pipe inside of the condenser of one of his models developed a leak. This sprayed cold water into the condenser and caused the steam to instantly turn to water. The vacuum force created by this accident was immense, drawing the piston down and crushing the bottom of the cylinder.[34] This happy accident demonstrated to Newcomen and his workers that injecting cold water into a condenser created "an incomparably powerful force" that would become key to the

[29] Hills 18
[30] Hills 20
[31] Hill 20 Rhodes 54-55
[32] Rhodes 54
[33] Rhodes 54 Hill 22
[34] Hill 25

engine's success. All Newcomen engines would intentionally employ this cold-water injection method of condensation.[35]

Over the next century, the Newcomen engine would revitalize the mining industry in England. Mines that were flooded out could be revitalized, and new, deeper seams could be exploited.[36] The challenge for Newcomen's engine was its irregularity and inefficiency. For pulling up on a bucket and draining mines, the regularity of the engine's cycling did not matter all that much.[37] However, this irregularity made it difficult for the engine to supply a regular rotary motion.[38] This limited the Newcomen engine's ability to directly power manufacturing machinery as later steam engines would. To provide rotary motion an engine needs to produce strokes identical in length, strength, and timing. What Newcomen's engine did was provide unbalanced strokes of an uneven power and timing as the piston paused at the end of every cycle to wait for a vacuum to form.[39] This variation in power and stroke could jam and damage delicate machinery.[40] So, contemporaries realized that it would not be appropriate to directly connect a Newcomen engine to an industrial mill. Instead, Newcomen engines were adapted to work with a waterwheel as a "returning engine". During the eighteenth century, many mills that relied on mechanized production used water wheels to power their machinery. During different times of year, the water supply to the wheel would vary.[41] A Newcomen engine could be set up to return water from the bottom of the wheel back to the higher retaining pond. This would keep water flowing over the wheel during dry seasons.[42] Set up in this way, it is possible to think of

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[35] Hill 25
[36] Rhodes 66
[37] Hill 23
[38] Hill 32-33
[39] Hill 32-33
[40] Hill 60
[41] Hill 37 Allen 170
[42] Hill 37 Allen 170

the water wheel as a device for smoothing out the action of the Newcomen engine to power a mechanized production floor.[43] The first returning engine would be installed at the Coakbrookdale Ironworks in 1742 and by the end of the eighteenth-century returning engines were in widespread use across England.[44]

The Tinkerer

The rotative engine was invented about half a century later by a Scotsman named James Watt. Watt was a well-educated instrument maker who had been hired by the University of Glasgow to service and repair a Newcomen engine that they had purchased for demonstrations.[45] Watt saw that there were some serious flaws in Newcomen's design. As an avid tinkerer, Watt set about modifying and improving upon what Newcomen had made. Watt realized that a good deal of heat energy was being wasted by the thick brass cylinder. As water was condensed inside of it, everything cooled down.[46] This issue was not dissimilar to the inefficiencies suffered by Savery's pump. Watt realized that if steam was condensed in a separate vessel, the heat inside of the cylinder would be preserved.[47] Watt's separate condenser dramatically improved the efficiency of the Newcomen engine. But there was still a loss of efficiency as steam leaked out of the top where the piston entered the cylinder.[48] To solve this problem, Watt teamed up with the ironmonger John Wilkinson. Wilkinson had been manufacturing cannons for the British Navy for many years using his improved technique of boring accurate holes for naval cannons.[49] Wilkinson's technique required the cannons to be cast as a solid piece. His machine would then

[43] Allen 170
[44] Allen 170
[45] Rhodes 67-68
[46] Hill 59
[47] Hill 59
[48] Hill 60 Winchester 51-52
[49] Winchester 45-46

clamp the cannon down and a rotating bit of hardened steel would be lowered slowly into the cannon, creating a precisely straight and smooth bore hole.[50] Watt hired Wilkinson to use his technique to produce an iron cylinder and piston with tight enough tolerances that a seal of grease would prevent steam from escaping.[51] The partnership was a success and Wilkinson's cylinder was accurately enough bored that the piston and cylinder walls created a snug seal with little friction and no escaping steam.[52] Now that the efficiency of the engine had been addressed, there was one further issue, that of translating the irregular motion of the piston to a regular rotative motion.

Watt smoothed out the action of the engine by connecting the cylinder to a flywheel with an offset crankshaft. A flywheel is a large, heavy, rotating wheel. Its purpose is to act as a sort of mechanical battery that stores rotative energy.[53] As the piston pulled on the crankshaft, it would set the flywheel spinning into motion. While the piston filled again with steam and waited for a vacuum to form, the flywheel would keep spinning, maintaining the rotational motion of the engine, and smoothing out its action.[54]

In 1769 Watt was granted a patent for his "*method of lessening the consumption of steam and fuel in fire-engines*".[55] It is clear from the title of his patent that Watt saw his most important improvements to the Newcomen engine as being those relating to efficiency. He had not yet grasped the importance of a rotational engine.

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[50] Winchester 46
[51] Winchester 51-53
[52] Winchester 53
[53] Hill 60-61
[54] Hill 60-61
[55] Hill 55

The Businessman

Struggling for funding and distracted by other obligations, Watt offered to sell some limited rights to his patent to the successful industrialist, Matthew Boulton, in 1775.[56] Boulton immediately recognized that Watts's engine was revolutionary, and he wanted to be the man to supply steam engines to "all the world".[57] So, instead of buying some limited rights, Boulton partnered with Watt. Boulton encouraged Watt to focus his efforts on improving the design of the rotative models of his engine, because, as an industrialist, he recognized the need to replace the waterwheel as the primary source of industrial power.[58] Together, they added improvement after improvement to the efficiency and power output of Watt's rotative engine. Ultimately, what they created would become the standard design for providing rotative power in countless applications.[59] By 1800, they had built 496 engines for pumping water, powering industrial machinery, and blowing air. Most of their engines were directly driving machinery for the industrial production of textiles.[60] They had made their mark on history.

After the expiry of Watts patent in 1800, there was an explosion in steam engine design.[61] Through the nineteenth century, steam engines powering industrial machinery spread all throughout Europe and North America.[62] On the sea, ships powered by steam could cross the ocean in record time and through inclement weather.[63] On land, railways allowed people and goods to be transported further and at a greater speed than they ever had before, shortening supply lines and connecting cities. In America, the railway allowed people to spread further

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[56] Rhodes 76-77
[57] Rhodes 77
[58] Hill 70
[59] Hill 70
[60] Hill 70
[61] Corfield 220
[62] Allen 179
[63] Allen 178

away from major ports and cities, facilitating the colonization of the Great American West.[64] The steam engine would grow to power the world for over a hundred years with many continuing to provide service until the late twentieth century.[65]

In 1722, Newcomen died and was buried in an unmarked grave.[66] He did not live to see Watt supersede his legacy. Altogether, 2000 Newcomen engines were put into service across Europe and America.[67] Newcomen had no way of knowing the impact his engine would have on the world. He had simply seen a problem and developed a solution, building upon ideas that had come before. Watt was a tinkerer who, like Newcomen, saw a problem and wanted to solve it. He had the ability to create a better engine, but he lacked the vision that would lead to its widespread adoption. Boulton was the one who saw the potential. Boulton, the businessman and industrialist, focused Watt's efforts and together they propelled the world into an age of steam.

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[64] Chronon 109-110
[65] Hill 291
[66] Corfield 219
[67] Corfield 220