

The rise of steam power

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Section **A** is a very brief summary of the rise of steam power, something that would be a mighty tome if the full story of the ideas, disappointments, successes and myths were to be recounted. Section **B** is a brief summary of Trevithick's contribution to the development of steam power, how he demonstrated it and how a replica of his 1801 road locomotive was built.

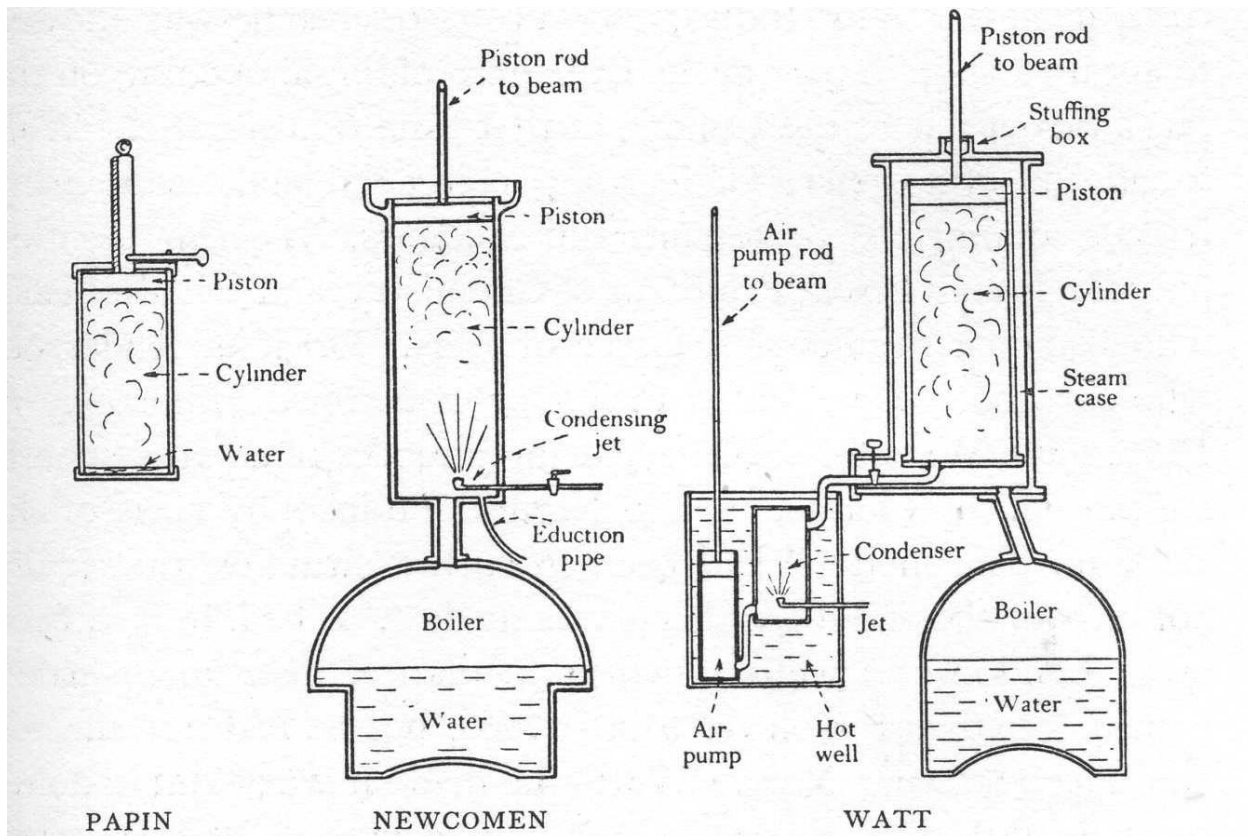
Those who study early steam should bear in mind that much of the 'history' that has come down to us is based upon the dreams of people seen as sorcerers in their time and bears little reality to what was actually achieved. Very few of the engines depicted in drawings actually existed and only one or two made any significant contribution to the harnessing of steam power. It should also be appreciated that many drawings are retro-respective and close examination shows that they would not work.

Many of those who sought to utilise the elusive power liberated when water became steam had little idea of the laws of thermodynamics or what they were doing. It was known that steam could be very dangerous but as it was invisible, only existed above the boiling point of water and was not described in the Holy Bible its existence and the activities of those who sought to contain and use it were seen as the work of the Devil. To this day, domestic steam cleaners are known as Steam or Dirt Devils.

The term 'engineer' was also unknown during the early days of steam and blacksmiths, who were also seen to be working with the Devil and fire to create metal from stone. They were protected from ridicule by authority because of their usefulness in the manufacture of weapons. There was a shortage of useful technology and materials.

Horses served as transport and industry was powered by water or wind. One purpose that could not be served by the established powers was the pumping of water from mines; inventors sought to fill this need.

After years of failure only three engines made any significant progress. Denis Papin, 1647-1712, is claimed by the villagers of Chitenay, France to be the first man to place a piston in a cylinder and move it by means of fire. He did this by converting water to steam. Moving a piston vertically upwards achieved little but Papin noticed that, as the engine cooled, the piston returned to the base of the cylinder. He therefore added pulleys to his piston rod and so was able to lift items. There is little record of this engine being put to any significant use. Papin also invented the pressure cooker and, after a mishap, the lever safety valve. A FRS, Papin died as a poor man in London.



Following Papin's work we have incremental improvements but they did not use the high pressure steam that the inventors of old had sought to conquer. They employed the atmospheric pressure that Otto von Guericke, 1602-1686, had demonstrated so famously with his two hemispheres and Papin had used to no clear advantage. Thomas Newcomen, 1665-1729, a blacksmith and Baptist minister of Devon introduced a beam over the piston to convert its falling movement into a lift. At last the mine owners could pump out their mines.

Sadly, the use of the Newcomen engine faced a serious drawback in Cornwall and Devon. To maintain the temperature of its major components in excess of 100°C it used copious quantities of expensive coal. All coal and iron had to be imported from South Wales by sea.

Between Papin and Newcomen another Devon man, Thomas Savery, 1650-1715, sought to benefit from the demand for a pumping engine by promoting his 'Miners' Friend'. He did this by issuing illustrations that have been used in history books to this day. However, the historians and the patent office of the day overlooked a couple of major flaws in his design. While, if he could produce a complete vacuum, he was able to raise water about 34 feet, his claim to pump it higher depended on the use of high pressure steam bearing on the contained water. Savery was unable to raise high pressure steam and, had he managed to do so, the introduction of steam to a vessel contain water at the ambient temperature would immediately condense the steam back to water.

Savery patented his useless invention and Newcomen had to pay him royalties until the extended patent expired. Several dozen Newcomen engines were erected in Cornwall, Josiah Wedgwood counted 13 in the one Parish of Gwennap, and they significantly aided the development of the Cornish mining industry for over 50 years. James Watt, 1736-1819, came into the picture following his paper entitled, 'Improvements to the Atmospheric Engine of Mr Newcomen', improvements that he patented. The Cornish mine owners, who were desperate for a more economical engine, placed two initial orders and Watt arrived with his wife at Wheal Busy, near Truro, in 1777. He made friends and worshiped with the Hornblower family of Baptists who had been erecting Newcomen engines in Cornwall.

Their friendship ended after Watt discovered that the Hornblowers had designed and patented engine that contravened his patent. He moved to Plain-an-Gwary (Cornish for dramatic performance area) in Redruth. He later moved to live at Cuscarne, outside the town.

Watt's improvement was the well-known addition of a separate condenser that considerably improved the thermal efficiency of the beam engine. Funded by Matthew Boulton, Watt engines replaced all the Newcomen engines in Cornwall. This was not the universal situation. Collieries that had surplus coal or industries close to coal mines continued to buy and use Newcomen engines as they involved a lower capital cost and avoided the charge that Boulton & Watt made to the conclusion of their extended patent. It was calculated on the improved performance of their engine over the Newcomen. Newcomen sold some 2,000 engines whilst Watt licenced the manufacture of about 500. Newcomen died a poor man in London.

Prior to his work on the Newcomen engine Watt had worked for years to produce rotary motion from steam. His various designs depended on the production of high pressure or 'strong' steam. His efforts to build a suitable boiler from iron bounded wood ended in disaster. The financial failure of his partner was followed by his work on a Newcomen model engine and provided a way forward that was technically simpler but it worked.

In 1769 a Frenchman called Nicholas Cugnot built a high pressure steam 3-wheeled road locomotive. It contained some remarkable innovations but lacked several components that would have made it viable. After travelling a short distance it is reported as having hit a wall and turning over. After being banished to Belgium Cugnot died a poor man in London.

Apart from Papin's cylinder and piston all subsequent boilers were riveted in a haystack, or kettle, shape and produced steam at little over atmospheric pressure. All engines were single-acting, pulling a beam downwards by a chain and quadrant.

Historians invariably estimate the output of a watt boiler at 3 psi but it must have varied. They also suggest that this pressure was sufficient to return the piston to its upper location prior to its power stroke. However, if this was the case,

- i. The piston would crumple the chain without moving the beam
- ii. Historians seldom, if ever, noticed that the other end of the beam was attached to a heavy wooden pump rod with iron fittings, often over 100 feet in length that weighed several tons. There were often counter balance beams below ground to compensate for its considerable weight. It is the weight of this rod that pulls the piston back up the cylinder and,
- iii. draws in a fresh charge of steam from the boiler.

Illustrators frequently show the cylinder of a single acting Watt pumping engine with its top closed by means of a gland or stuffing box that seals off the atmospheric pressure that drives the engine. Glands, opening cocks, parallel motion, flywheels and sun and planet all came some years later with double acting rotative action.

Watt took the design of the atmospheric engine to its limit. Boulton had brought in John Wilkinson, 1728-1808, an armaments manufacturer from Broseley in Shropshire to machine the cylinders while the boiler and ancillary parts were usually made by local blacksmiths. It was necessary to build the engines larger to produce the additional power required as the mines deepened. It was bespoke terminal technology that was becoming cumbersome and expensive. Watt, who never enjoyed good health, had been depressed by the financial shenanigans of his partner Matthew Boulton so he concluded his partnership and left Cornwall following the expiration of his extended patent in 1800. He had lived in Cornwall, with occasional

visits to Birmingham, for 23 years. His son, James Watt, Jnr, re-established the financial credibility of the company and his father died a wealthy man.

Subsequent engines built by James Watt & Co Ltd, as installed in Brunel's Great Eastern and elsewhere, had nothing to do with James Watt and were equipped with Trevithick-type high pressure cylindrical boilers.

The steam power scene was now open for Cornishman Richard Trevithick, 1771-1833, to introduce the high pressure steam engine. His initial desire was to replace the horse as a means of transport. All his demonstration engines, including models, had wheels. John Harvey, his father-in-law and a former blacksmith, had established an iron foundry at Hayle in Cornwall and was willing and able to cast the first high pressure cylindrical boiler.

Apart from Papin's cylinder and the use of coal and water there were no features of Trevithick's engine that were interchangeable with Watt's. Trevithick's was entirely new technology that required a great deal of thought about the many features that enabled it to work first time.

- i. Furnace within the boiler
- ii. A complicated, riveted return furnace tube unlike anything that had previously been constructed.
- iii. Waste steam exhausted to atmosphere and used to pre-heat charge water to the boiler.
- iv. Exhaust steam injected into chimney to form blast pipe. (Letter to Giddy, April 1804 detailing how it improved performance)
- v. High pressure pump to replace water in boiler.
- vi. From 1803, a fusible plug.

Engines built internationally in accordance with the designs of Richard Trevithick would run into millions.

Building a replica of Trevithick's 1801 road locomotive

Like the dodo we have no definite idea what the first successful road locomotive looked like. Francis Trevithick was not born when his father made the historic journey and his subsequent drawing was based on the memories of men who could not be found in any census records. It was published 71 years after the event.

Our engineer, John Sawle, clambered over the original Trevithick stationary 'Puffer' engine built by Hazeldine of Bridgnorth and now in the Science Museum. Using a camera, note book and tape measure he carefully recorded the dimensions of the engine and produced the drawings to which the replica was built. The oak chassis and artillery wheels followed military design of the time. Total weight is about 4½ tons.

The original boiler and furnace tube were masterpieces of design and craftsmanship. Constructed of shaped and riveted wrought iron the tube was water, fire and pressure proof; ours was welded. Both contained fusible plugs.

The original beam connecting the piston rod to the connecting rods was also copied faithfully. Casting the new beam required specific high tension steel and a computer stress analysis prepared in Paris. Nothing is recorded of the percentages of carbon or other additives used in the casting of the original beam. The suitability for purpose of that finished beam was decided by the eye and experience of the blacksmith guided by the Devil. There are no records of any Puffer beams breaking.

The beam and only one of the two con rods drove just one wheel. This considerably increases the strain on the components. Trevithick was well aware that wheels travel different distances when negotiating curves.

All cylinder and valve components required meticulous machining in Trevithick's day to contain the high pressure. He used 47 psi, we start at the foot of 'Camborne Hill' with 100 psi. Valves consist of a four-way to supply and exhaust steam from the double acting cylinder and a directional valve to choose forward and reverse motion.

The artillery wheels are made of oak fellies with ash spokes and are equipped with steel tyres; they weigh up to 2 cwt each. His next vehicle, the 1803 London Carriage, drove one 8' wheel at a time through a series of toothed wheels. This provided the opportunity to build the drive with different numbers of teeth to each wheel, so creating two-speed transmission.

Trevithick's 1804 tram track locomotive ran from Penydarren to Abercynon near Merthyr Tydfil in South Wales, a distance of 9½ miles several times. It pulled a train of waggons with 10 tons of iron onto which 70 passengers clambered. He reported that the locomotive required no water on the initial journey. This was seen by historians as an indication of its efficiency. They did not notice that the journey was mainly downhill. In a letter to Davies Giddy (later Gilbert) Trevithick described the positive effect he had noticed on the performance of the furnace after he had fed the waste steam up the chimney. This important blast pipe was subsequently claimed and patented by a number of people including George Stephenson.

Trevithick's exploits in 1804 were followed by a number of similar locomotives being built around the country for commercial purposes. Stephenson's *Rocket* won the Rainhill Trials for passenger locomotion 25 years later.

Following the success of the rail journey Humphry Davy wrote to Davies Giddy, MP, FRS, often described as Trevithick's lifelong friend and mentor, in October telling him to take the credit for the invention of the high pressure engine and that Trevithick was the mere engineer who worked to his instructions. He did, and continued to do so all his life, omitting Trevithick completely from his lectures and crediting Watt with the development of the steam engine in Cornwall and elsewhere.

Trevithick knew nothing of this deception and continued to trust Gilbert all his life. Trevithick was employed as a design engineer by John Hall & Co of Dartford where he lived in the best hotel in town and died there in 1833. A valediction that he was reported to have written and upon which much of his final years have been based by historians was written by Giddy/Gilbert.