The Origins of the Steam Engine

Fifty years before James Watt came on the scene Thomas Newcomen built practical steam engines to pump water out of mines. What is known of these engines and how did they influence later ones?

by Eugene S. Ferguson

If one had a handbook of human history with a synoptic chart that opened out at the back, one might expect the chart to reduce the industrialization of England in the 18th century to the words "James Watt," "steam engine" and "textile mills." This familiar view is misleading on two counts. Watt did not invent the machine that supplied power to the looms of the textile mills. Steam engines had been put to work 50 years before Watt appeared on the scene, and the industry that created the demand for them was not weaving but mining. At the beginning of the 18th century two Englishmen from Devonshire, Thomas Savery of Shilston and Thomas Newcomen of Dartmouth, built steam-powered pumping machinery for the drainage of mines. The need for a way to remove water from mines had become more and more pressing as the mineral resources of England were exploited during the 17th century. The operators of tin mines in Cornwall and lead mines in Derbyshire were waging a losing battle against water seepage as their mines were dug deeper, and many coal mines around Birmingham and Newcastle were threatened with flooding as the inflow of water overcame the pumps then available. Savery's engine never succeeded as a mine pump, although it was useful for other purposes; Newcomen's did provide the power to lift water from mines.

The Newcomen engine also succeeded, two generations later, in stimulating the curiosity and imagination of James Watt. In 1769 Watt patented an engine soon brought to commercial status by industrialists who realized that its superior thermal efficiency would enable them to make greater practical use of steam power. The Newcomen engine should not, however, be considered a mere taking-off point for the genius of Watt. Its impact on the technology and economics of mining is today symbolized by the monotonous bobbing of the pivoted "walking beams" of oil-well pumping rigs, a familiar sight in the southwestern U.S. The vertical pump shaft is guided at its upper end by an odd protuberance on the beam called, in the graphic language of the industry, a horsehead. Whether or not the builder of the first such oil-pumping rig was aware of his source, he had borrowed these elements from a Newcomen engine originally used to pump water [*see illustration on opposite page*]. In 250 years the power unit has evolved from a steam cylinder to an electric motor, but its function—to pull one end of the beam down—has not changed at all.

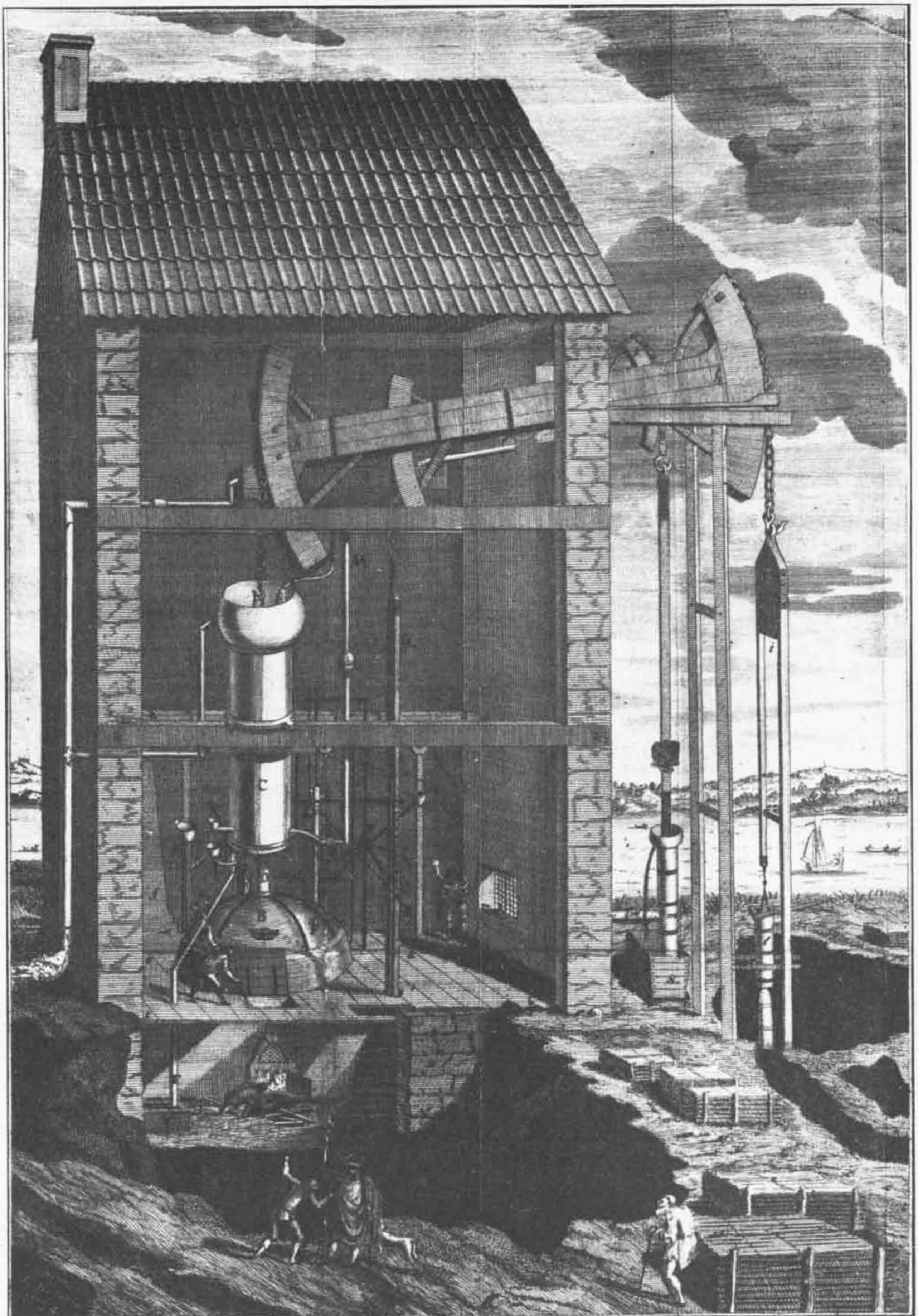
In Newcomen's design one end of the beam was secured to the pump shaft and the other end was chained to a piston that fitted into a vertical steam cylinder. When steam supplied to the cylinder from a boiler directly below it was condensed by the injection of water, the resulting vacuum enabled the pressure of the atmosphere to force the piston down, thus drawing the beam down on one side and the pump rod up on the other. Long after the steam engine was being used for purposes other than pumping it retained the overhead beam of Newcomen's design. Watt himself experimented in 1770 with turning the cylinder upside down in order to eliminate the beam, but he quickly and permanently abandoned the idea.

Little is known about Thomas Newcomen, the man whose innovations were so original, influential and enduring. He was born in Dartmouth in 1663, made a living as a seller and perhaps small-scale manufacturer of iron products and died in London in 1729. The recent tricentennial of his birth gave impetus to the study of his life and work; such study, including this critical review of the Newcomen engine, would scarcely have been possible were it not for the dedicated men who in 1920 in London organized the Newcomen Society for the Study of the History of Engineering and Technology. The members of this group, the first to take a serious interest in Newcomen as an individual, combed the records for the origins and later history of the steam engine, publishing their findings in the *Transactions* of the society.

The source materials they uncovered tell us more about the state of technology at the time than about the events of Newcomen's life; nothing is revealed of his formal and informal education, the actual sources of his ideas and the steps by which his major innovations were thought out. It is unlikely that we shall ever learn the details of the steps taken by Newcomen during the 10 years he spent developing his engine. He was not prominent during his lifetime, and although his engine won immediate acceptance, it was seldom linked with his name, being known merely as the "fire engine" or "atmospheric engine." In this article I shall review the antecedents of the engine he designed and, as far as I am able to reconstruct it, the period of development immediately preceding its appearance.

A glance at the dozens of well-illustrated books devoted to machines that were published in Italy, France and Germany from the time of Georgius Agri-

NEWCOMEN ENGINE at a mine at Dannemora in Sweden was illustrated in a book of 1734 on Newcomen's principles; the illustration is reproduced on opposite page. The author was the Swedish engineer Mårten Triewald. Illustration describes the engine as the "Dannemora fire and air machine."



Dannemora Eld och Luft Machin,
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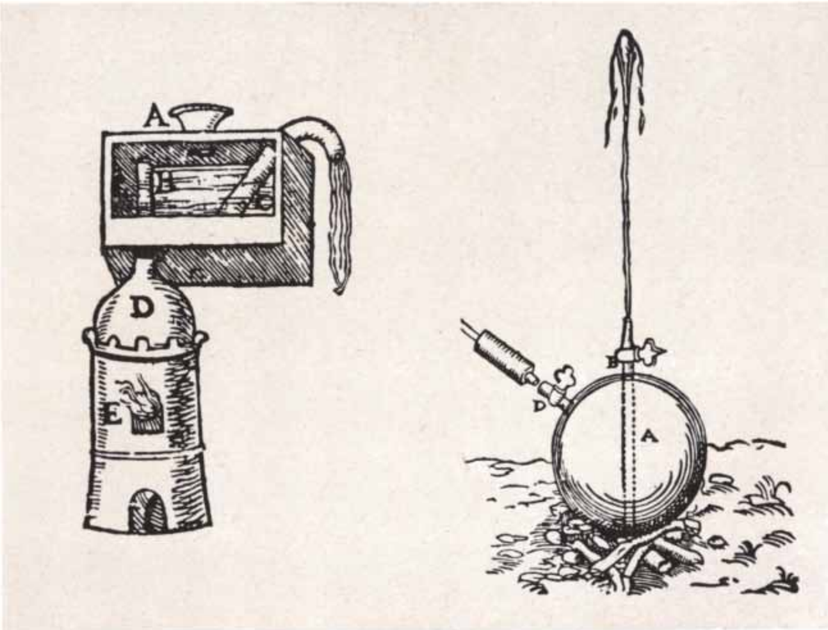
Underdån ödmiukast Dedicerad af Mårten Triewald.



STEAM DEVICES of 16th century raised small amounts of water. At left is an apparatus of Giambattista della Porta; water poured into chamber *B* through funnel *A* is raised through pipe *C* by steam generated in flask *D*. At right is a device of Salomon de Caus adapting same principle to produce a fountain through the generation of steam in a copper sphere (*A*).

cola's *De Re Metallica* (1556) onward indicates that the problem of water-raising was one that occupied many mechanics and mechanical philosophers in the advanced countries of Europe. Except for Agricola's treatise on mining, which gave details of 14 kinds of pump for removing water from mines, the books were concerned less with mine drainage than with pumping water for town and castle water supplies and for the operation of fountains. Nevertheless, the techniques of pumping were well known and widely discussed. Some of the devices employed were an endless chain of buckets, the Archimedean screw and the rag-and-chain pump, in which a series of rag-wrapped balls, spaced a foot or two apart on a continuous chain, were drawn vertically upward through a wooden pipe, each forcing some water ahead of it. There were many alternative machines using manpower or horsepower for the hoisting of ordinary tubs of water. During the 17th century the possibility of using steam or gunpowder as a motive power was also being explored.

It has been said that science owes more to the steam engine than the steam engine owes to science. Such a generalization seems particularly inappropriate with respect to a machine that exemplifies the overlap between the empirical and the theoretical stages of the Industrial Revolution. Although it is true that a clear understanding of the thermodynamic phenomena in the steam engine was not attained until around 1860, it is equally true that the sequence of ideas apparent in the work of Galileo, Torricelli and Pascal in establishing the fact of atmospheric pressure, and of von Guericke, Huygens and Papin in devising ways to make atmospheric pressure do work, was an indispensable prerequisite of the Newcomen engine.

Close to the Newcomen engine chronologically but not conceptually was the steam-powered machine patented by Thomas Savery in 1698. This engine, which promised to solve the problem of mine flooding, incorporated elements and principles not shared by the Newcomen engine and can be traced to a wholly different line of development. Savery, a gentleman of leisure and Fellow of the Royal Society of London, exhibited a model before the society in 1699. His engine consisted of a vessel in which steam was condensed to produce a vacuum, whereupon the vessel was filled by water rising through a suction pipe [*see illustration on opposite page*]. Steam at high pressure was then admitted to the same vessel, forcing the water to a higher elevation. The machine was a combination of steam pumping devices built or suggested earlier by Salomon de Caus and R. d'Acres and probably well known in Savery's circle.

In 1702 Savery expanded his patent application in a small book entitled *The Miner's Friend.* Here he addressed himself to the "Gentlemen Adventurers in the Mines of England: I am very sensible a great many among you do as yet look on my invention of raising water by the impellent force of fire a useless sort of a project that never can answer my designs or pretensions; and that it is altogether impossible that such an engine as this can be wrought underground and succeed in the raising of water, and dreining your mines.... The use of the engine will sufficiently recommend itself in raising water so easie and cheap, and I do not doubt but that in a few years it will be a means of making our mining trade, which is no small part of the wealth of this kingdome, double if not treble to what it now is."

In spite of Savery's optimism, the metalworking techniques at his command were inadequate to solve the problem of containing steam at several atmospheres of pressure. Hence the Savery engine was practical only in situations other than the one for which it was originally intended. The most successful application of the engine was in pumping water into building or fountain reservoirs that were no higher than about 30 feet, which called for only moderate steam pressure.

The Newcomen engine soon preempted the role of draining the mines, but the Savery engine was the first to be employed (around 1750) to turn machinery. For this purpose the engine pumped water into a reservoir some 15 or 20 feet above that supplied a conventional water wheel. Throughout the latter part of the 18th century the Savery engine was built in considerable numbers and used by manufacturers who could not or would not afford the larger, more efficient but initially more expensive Newcomen and Watt engines. As late as 1833 at least five Savery engines were at work in France; the engine was reinvented about 1870 in Germany, perhaps also in England. Now known as the pulsometer, it went on to a new career of pumping water containing solids in such applications as the drainage of shallow excavations.

The problem of following the sequence of events in the development of the Newcomen engine points up the meagerness of available source materials. What little information Newcomen's contemporaries have left us requires careful interpretation. One popular scientific lecturer of the early 18th century, John Theophilus Desaguliers, described him as an "ironmonger" and "Anabaptist." This is the way he has been described by modern writers oblivious to the fact that "ironmonger" has come to imply "peddler," or perhaps "junkman," and that "Anabaptist" suggests the outlandish. Thus Newcomen is likely to be thought of as a ragged, gaunt pusher of a handcart, waiting for Dickens to be born so that he could get into one of his books.

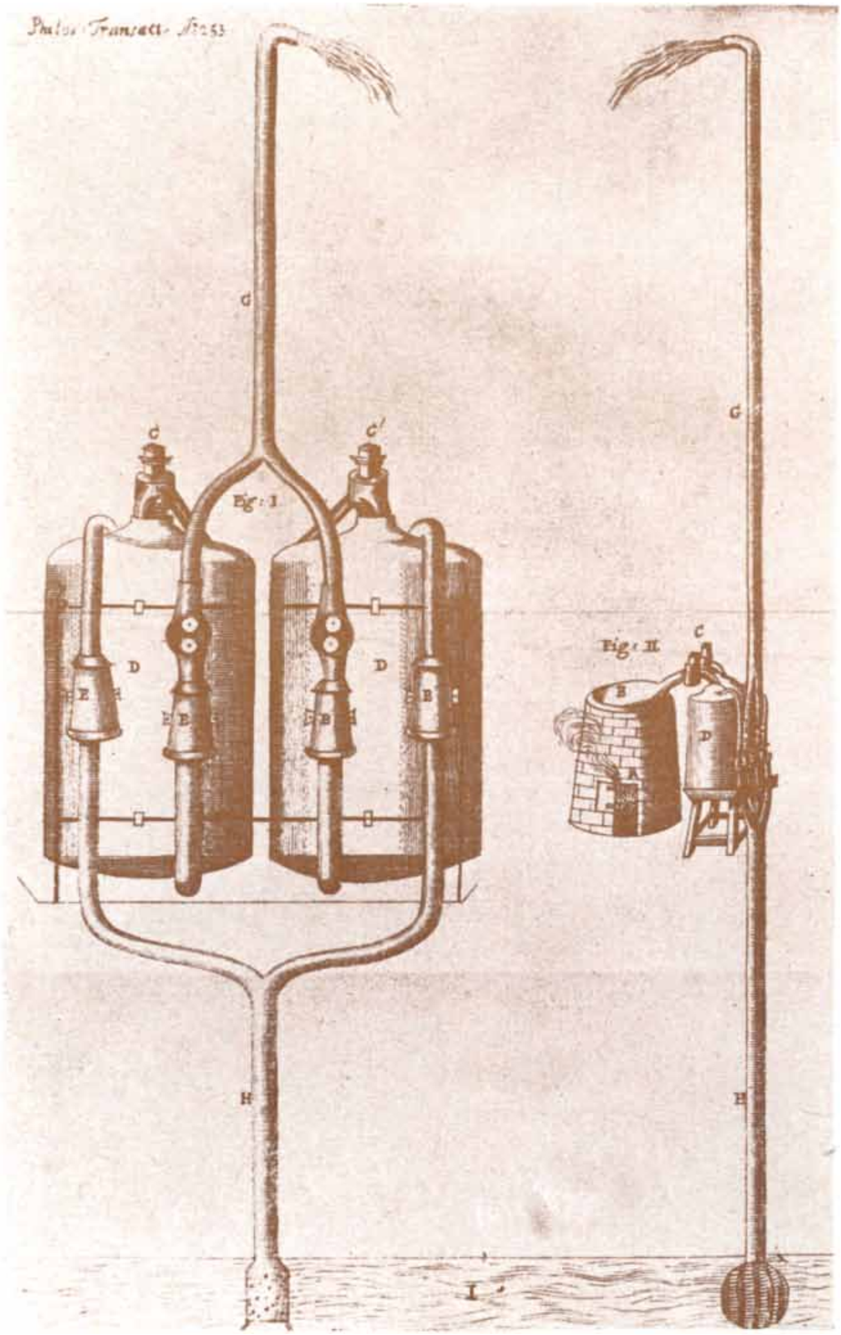
The background of his assistant, John Cawley, is even less distinct. Desaguliers called him a glazier; another man who could have known him said he was a plumber. Elsewhere he is referred to as a brazier or coppersmith. This description seems proper because an ironmonger was a dealer in hardware and industrial supplies, sometimes manufacturing what he sold. He might have had an iron foundry as part of his establishment; he usually employed braziers and tinsmiths; he was likely to have a lathe and a smithy. It has been suggested, I think reasonably, that the ironmonger rather than the millwright (who generally built in wood) was the predecessor of the mechanical engineer. So we can forget the picture of Newcomen the indigent peddler and accept the more plausible likeness of a man well skilled in the machinery trade.

As for the significance of the work Newcomen did in developing the steam engine, Desaguliers states: "If the Reader is not acquainted with the History of the several Improvements of the Fire-Engine since Mr. *Newcomen* and Mr. *Cawley* first made it go with a Piston, he will imagine that it must be owing to great Sagacity, and a thorough Knowledge of Philosophy, that such proper Remedies for the Inconveniences and difficult Cases mention'd were thought of: But here has been no such thing: almost every Improvement has been owing to Chance."

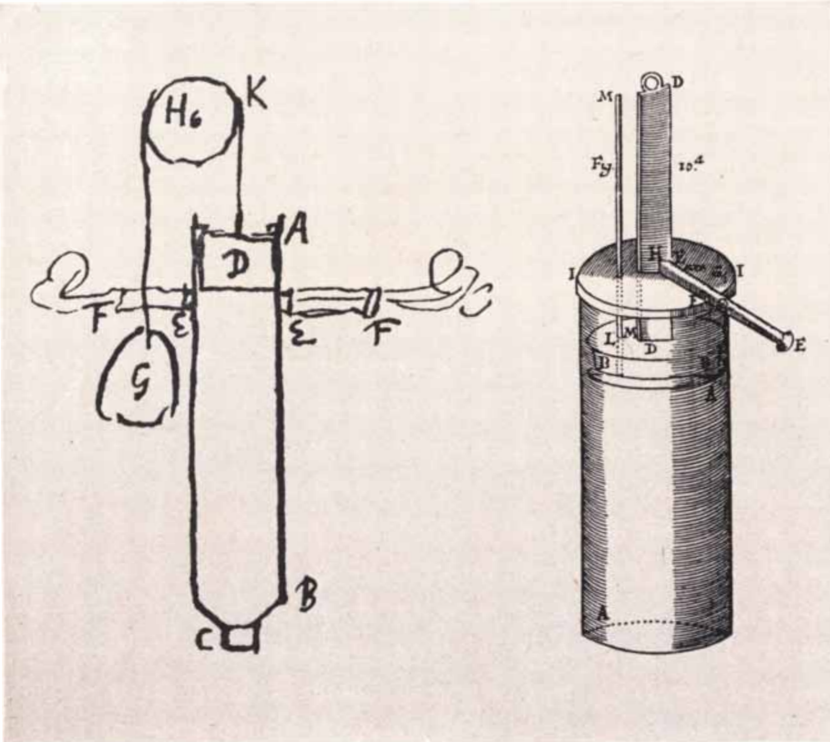
Further detraction—or inverted praise—came from Mårten Triewald, a Swedish engineer who took plans for a Newcomen engine back to Sweden with him in 1726, attributing the design to the Almighty, who "presented mankind with one of the most wonderful inventions that has ever been brought into the light of day, and this by means of ignorant folk who had never acquired a certificate at any University or Academy." Triewald did mention, however, that Newcomen worked on his machine "for ten consecutive years."

Since Desaguliers and Triewald, our principal sources, were contemporaries of Newcomen's, it is perhaps presumptuous to question their judgment. But contemporaneousness does not ensure accuracy, and Desaguliers is known as a kind of press agent of science and the arts. He was the first to publish the absurd story about Humphry Potter, the boy who, while attending a manually controlled Newcomen engine, invented the automatic valve gear in order to keep the engine running when he went fishing. The work of both authors shows them to be vain and opinionated, and it is natural to wonder on what occasion Newcomen had pricked their pompous balloons.

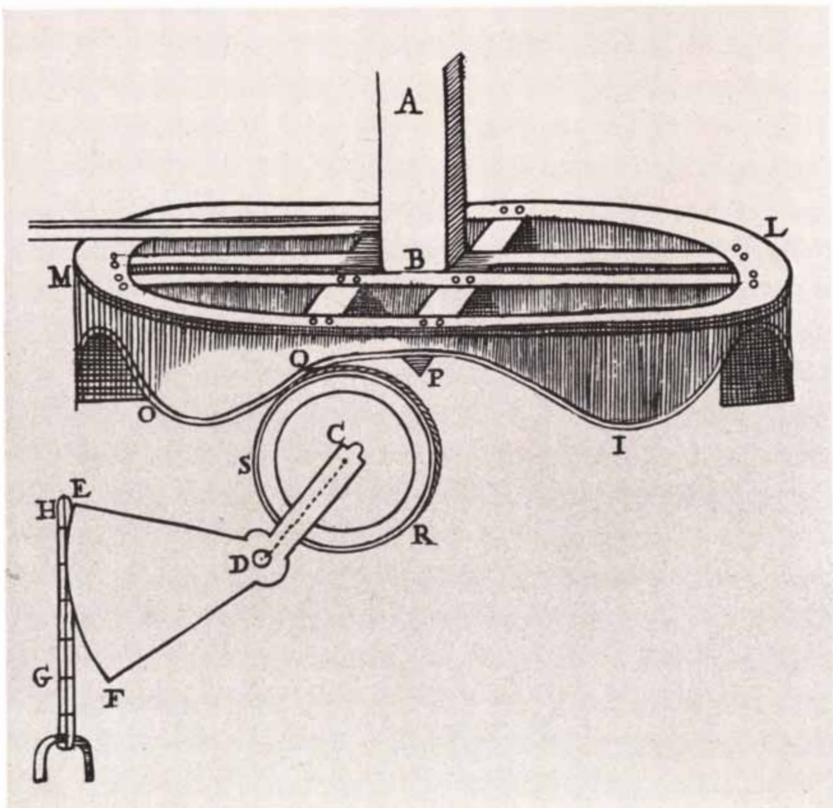
The scant biographical information does not tell us unequivocally that Newcomen's design was complete when the engine was set to work near Birmingham in 1712. L. T. C. Rolt has recently assembled evidence that suggests the exist-



MINE PUMP designed by Thomas Savery in the late 17th century envisioned condensation of steam in vessels *D* to produce a vacuum, which would create suction to draw water up from the mine to fill the same vessels. High-pressure steam would then be introduced to dispose of the water through pipe *G*. The pump did not work in mines because metalworking techniques to contain high-pressure steam were not available. It did serve to pump water into low reservoirs for use in buildings and fountains; steam pressures for that were moderate.



PRECURSORS OF NEWCOMEN ENGINE included (*left*) an idea sketched in a letter by Christian Huygens for using gunpowder to force air out of a cylinder; as remaining air cooled, piston *D* would drop. At right is design by Denis Papin using steam to make vacuum.



CAM ARRANGEMENT of a pump in 1696 was a precursor to the arch head devised by Newcomen. Horsepower turned scalloped cam, which raised and lowered wheel *C* around fixed pivot *D*, producing a pumping action by blade-shaped device attached to a lift pump.

ence a few years before 1712 of one or more unsuccessful Newcomen engines in Cornwall, near the inventor's home in Dartmouth. This would certainly make more credible the appearance of a definitive machine in 1712. In any case, a virtually anonymous ironmonger working in Dartmouth would hardly travel 175 miles to Birmingham, as Newcomen apparently did, to erect an engine unless he had connections farther afield than his home city. Although I cannot be certain, it seems probable to me that Newcomen was no stranger to London and that he quite possibly had traveled to the Continent, where he might have seen some of the great water-driven pumping engines around Paris. Just as Americans in the early 1800's went to England to learn the latest techniques in engineering, so in the 1700's Englishmen went to the Continent.

The design of the engine built by Newcomen in Birmingham in 1712 was, if not definitive, remarkably near completion. Certainly by 1717 it had been given its final form; we have an engraving made of the engine in that year. Fifty years later John Smeaton was to improve Newcomen's machine by determining after methodical empirical investigation the optimum operating conditions and proportions of parts of the engine, but Smeaton did not tamper with the inventor's essential design.

Even in its earliest manifestations the Newcomen engine was simple enough so that observers could understand its operating principle and cyclical sequence of events as soon as an explanation was provided. A vertical steam cylinder, fitted with a piston, was located under one end of the large, pivoted working beam; the piston rod was hung on a flat chain secured to the top of the arch-shaped head of the beam. Steam was supplied to the cylinder by the boiler directly below it. A vertical lift pump was located under the other end of the beam and the pump rod hung on a flat chain secured to the arch head just above it. Thus both the piston rod and the pump rod moved vertically, always tangent to a circle whose center was at the pivot of the beam.

A working stroke began after the steam cylinder had been filled with steam, at a pressure just slightly above atmospheric, from the boiler. The pump end of the working beam was held down by the weight of the reciprocating pump parts, which extended down into the mine. The steam-admission cock was closed, and water was then injected into the cylinder in order to condense the steam and produce a vacuum. The atmosphere, acting on the top of the piston, pushed the piston down into the evacuated cylinder, which caused the pump rod to be lifted by the other end of the beam. The cycle of operation was completed by again admitting steam to the cylinder in order to allow the pump end of the working beam to go down. As soon as the cylinder pressure reached atmospheric, the spent injection water was discharged into a sump.

The cylinder was large. The first engine cylinder was 21 inches in diameter and had a working stroke of more than six feet. The effective vacuum was about half an atmosphere, enabling a 21-inch piston to lift unbalanced pump parts and water weighing one and a quarter tons. Operating at 14 working strokes a minute, the engine would develop about six horsepower. Later engines increased in size to a cylinder diameter of seven feet and a stroke of 10 feet and developed well over 100 horsepower.

The late Henry W. Dickinson, author of the current standard history of the steam engine and a principal founder of the Newcomen Society, recognized that Newcomen's contribution was the "first and greatest step" in the development of the modern steam engine, but he diluted the effect of this judgment by writing: "When we look into the matter closely, the extraordinary fact emerges that the new engine was little more than a combination of known parts."

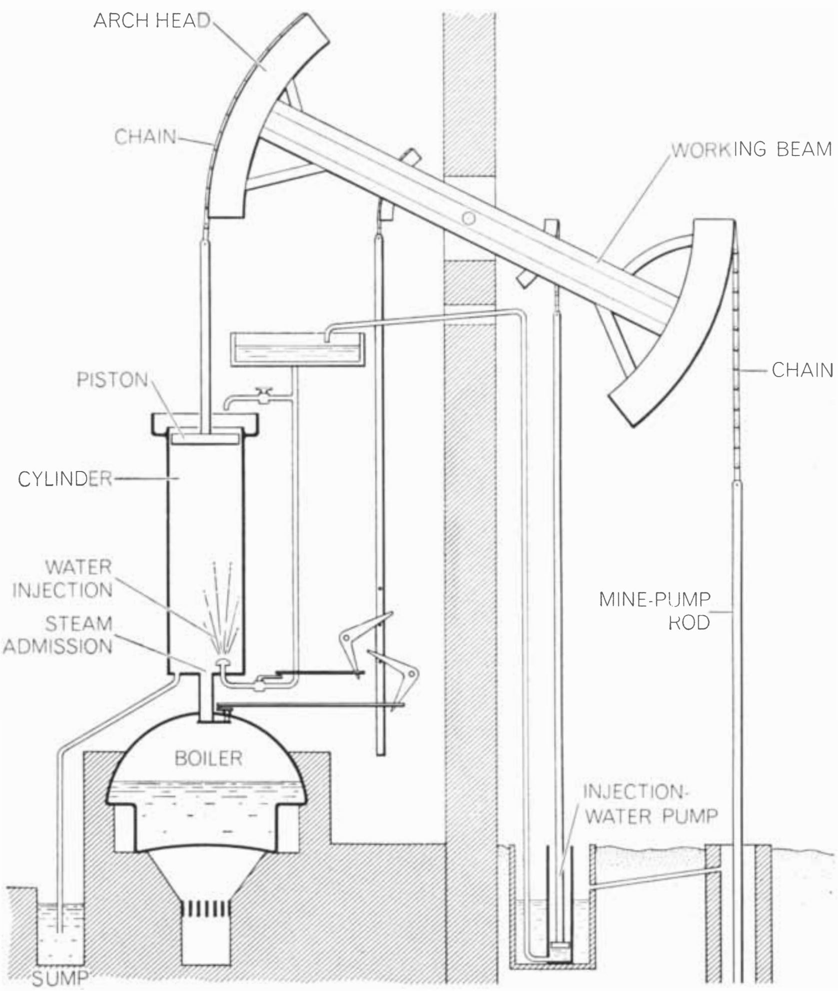
This statement brings to mind a remark made in 1853 by a correspondent of *Silliman's Journal:* "It appears that the human mind cannot arrive at simplicity except by passing through the complex; it is like a mountain more or less elevated, whose heights must be overcome before the plain at the opposite base can be reached: and when reached, the level seems to be that of the plain left behind. So when a simple solution of a problem is arrived at, we think it an easy natural thought and almost self-evident."

This, it seems to me, describes the problem we have in looking at the innovations of Thomas Newcomen from a 20th-century vantage point. In retrospect the idea of the steam engine is a natural thought, modified only by our occasional impatience with Newcomen's inability to see some obvious further development, such as the addition of a crank and flywheel, which came two generations later (shortly after having been rejected as impractical by so capable and forward-looking an engineer as John Smeaton). It is not easy for the human mind to put what is now obvious back into the box labeled "Unknown."

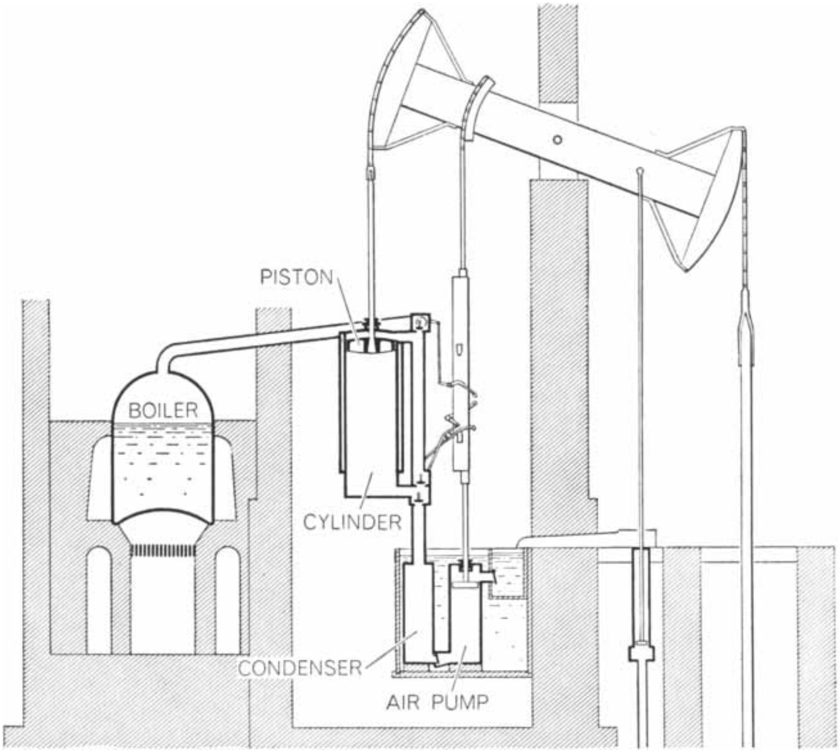
In discussing Newcomen's achievement with reference to the "known parts" of the engine it should be noted that he was not simply a clever compiler of mechanical elements. He did not employ many devices, including the crank and flywheel, that were vastly better known than some he made use of in his "combination of known parts," and most of those he did use he modified in such a way as to make the distinction between adaptation and invention seem artificial.

Consider Newcomen's use of the steam cylinder and piston. The line of development leads straight from von Guericke through Huygens and Papin to Newcomen. The cylinder fitted with a piston and evacuated by the condensation of steam was clearly present in Papin's design published in 1690 and republished in 1695, and we ought to assume that Newcomen knew at least as much about Papin's work as had been published. The steam in Papin's cylinder, however, was to be condensed by cold water dashed on the outside wall. Newcomen's essential improvement was to inject water directly into the cylinder, which sped the condensation and enabled the engine to operate at 12 or 14 strokes a minute instead of three or four.

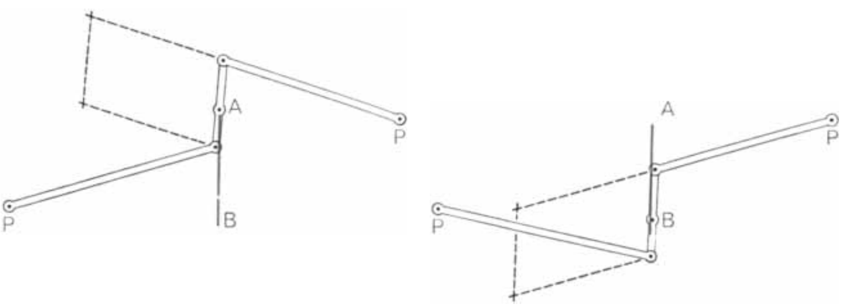
One of Newcomen's experimental engines had employed a water jacket around the steam cylinder for cooling, and it may be, as Triewald reported, that the change from external to internal cooling resulted from the accidental leakage of jacket water into the cylinder, which "immediately condensed the steam, creating such a vacuum that... the air, which pressed with a tremendous power on the piston, caused its chain to break and the piston to crush the bottom of the cylinder as well as the lid of the small boiler." Even if this report is accurate, Newcomen was still faced with the nice diagnostic problem of determining from the wreckage what had caused the



SUCCESSFUL ENGINE by Newcomen introduced steam into a cylinder that was then cooled with injection of water, creating partial vacuum. Atmospheric pressure forced piston down to achieve pumping; weight of mine-pump rod and equipment then raised piston for new cycle.



CONTRIBUTIONS BY WATT to the steam engine included the development of a separate condenser, as depicted here. Newcomen had effected the condensation in the main cylinder.



PARALLEL MOTION was another major contribution by Watt; it kept piston rod vertical as beam end moved in an arc. Three key elements (*solid lines*) worked from fixed pivots *P* so that rod end, at center of vertical element, moved along line *A-B*. Watt's final version made use of a parallelogram linkage (*broken lines*) that made whole apparatus more compact.

sudden smash. Serendipity in no way diminishes Newcomen's role in the innovation of injection condensation.

In his use of the boiler Newcomen was adopting a thoroughly developed "known part." Made of copper, the boiler probably was derived directly from the brewer's kettle. Since the steam pressure was low—Newcomen set his safety valve to open at about 1.5 pounds per square inch above atmospheric pressure—the difficulties of design and construction were few. Indeed, the boiler was similar to the one built by Savery.

The full synthetic ability of Newcomen, and his judicious critical sense, are revealed in his treatment of the working beam, the pump and the valve gear. The working beam and pump can be examined together, because their appearance is that of a greatly enlarged pump handle or well sweep attached to a common reciprocating lift pump. Before Newcomen's day few, if any, mines in England were drained by lift pumps attached to beams, pump handles or sweeps. Where the topography of the mining district permitted, long drainage tunnels called adits were dug from the lowest mine level to a lower open valley in the vicinity. Although the adits were small in cross section, some of them extended for two miles or more. Even after a mine was deepened beyond its adit level, water had to be pumped only as high as the adit. When surface water was available, an underground water wheel, receiving its water from ground level and discharging into the adit, would operate a lifting device of some kind, usually a chain of buckets.

In some larger works, where horses could be used, the water was lifted in great tubs by a whim, or horse gin. The hoisting rope was wound on a horizontal drum geared to a vertical shaft. The vertical shaft, fitted with a hub with radiating arms, was dragged around by horses hitched to the ends of the arms. In smaller mines, where only manpower was available, a horizontal drum turned by hand cranks was used to hoist buckets or drive a rag-and-chain pump.

If Newcomen had seen a copy of Agricola's mining book, he would have found reciprocating lift pumps in profusion, but he would have come away from the treatise with the distinct impression that the proper way to move the rod of the lift pump up and down was to hang it on a crank arm, that is, to employ a crank and connecting rod. There is one simple beam pump in Agricola, but it is a small one operated by the power of a single man.

Among the actual devices that Newcomen might have seen was a large overhead pivoted beam, without arch heads, in the horse-driven water pump at York House in London. The London Bridge waterworks, although they employed cranks and connecting rods, had the lower third of a large pulley cut away in a manner that faintly suggests the arch heads at the ends of the Newcomen engine beam. The almost complete absence of the arch head from pump beams in the illustrations that Newcomen might have seen is most striking. A sketch in Leonardo da Vinci's notebooks could hardly have been known to Newcomen because the notebooks were effectively buried until the 19th century. Only one illustration remains as the possible—or probable—source of Newcomen's arch heads. In a book by Venturus Mandey and James Moxon—*Mechanick-Powers: or, the Mistery of Nature and Art Unvail'd,* published in London in 1696—there is a cam-operated pumping device that clearly shows the sector-and-flat-chain arrangement adapted by Newcomen, who changed the shape of the beam from curved to straight. The drawing in the Mandey and Moxon book was copied directly from an earlier work edited by Philippe de la Hire, a French mathematician and member of the Académie des Sciences, who had directed the building of such a pump to supply water to a castle near Paris.

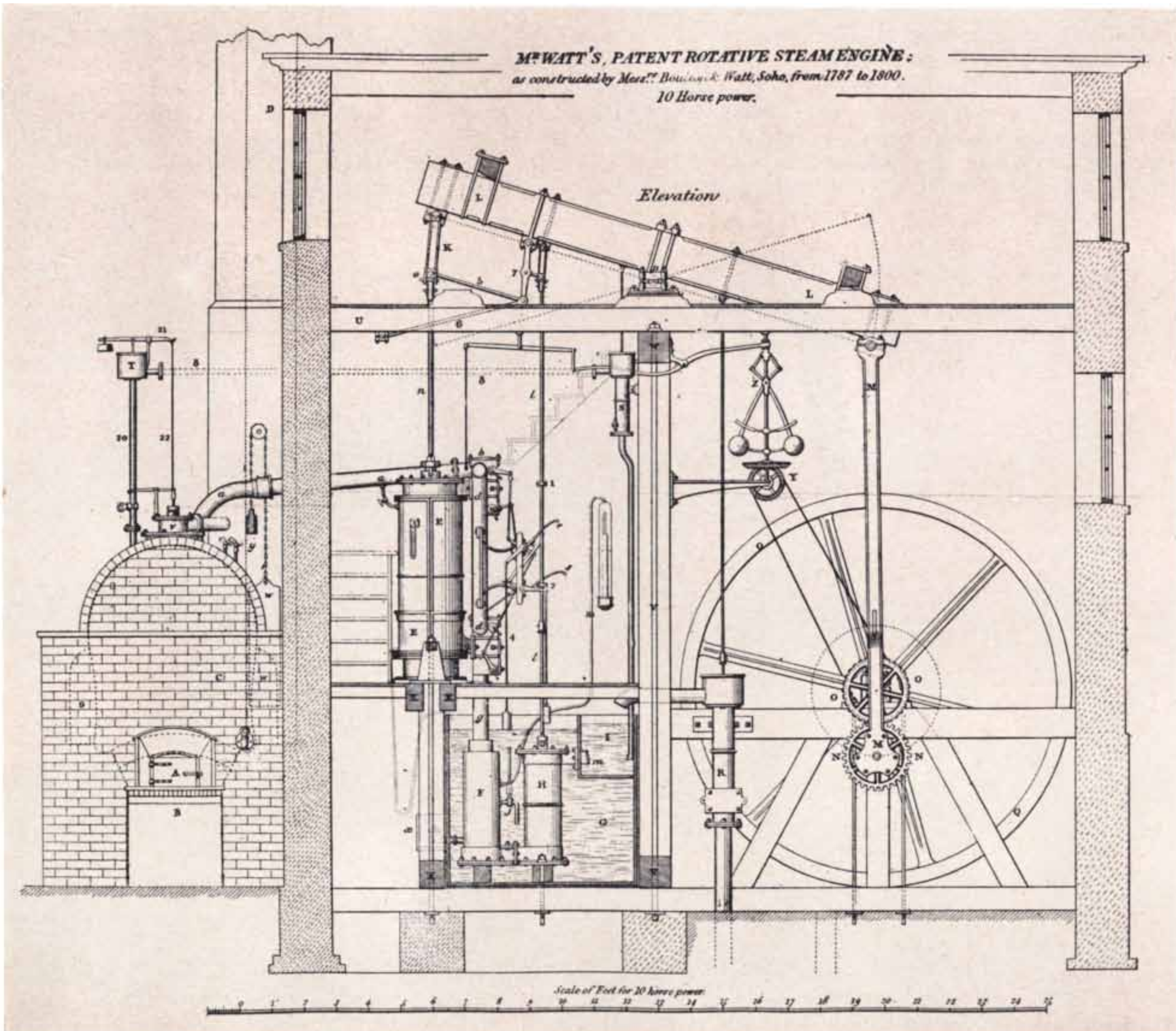
Thus the working beam of the Newcomen engine appears to be an elegant adaptation, not a copy, of ideas that existed before he designed his engine. I have labored this point in order to emphasize the fact that Newcomen was not merely adapting the steam cylinder to a widely used system of water-raising. His engine was a new and original system in itself.

The origin of the valve gear, which enabled the engine to operate automatically—opening and closing valves as required for the sequence of operations—is similarly obscure. The idea may have been suggested to Newcomen by a control mechanism of the automata—knights, maidens and animals—that performed at an appointed hour in the great medieval clocks. The Newcomen engine valve gear was a sequential control; it remained for Watt to supply a regulatory feedback control system. Newcomen's system, however, was much more involved than, for example, the control of the rate of a common clock.

Even after all the elements of the steam pumping engine had been settled on, however, there was still the problem of the physical arrangement of the elements. Pictures of the gaunt and unsymmetrical profile of the Newcomen engine set against the English landscape, with its awkwardly tall stone enginehouse and its outlandish protruding beam threatening to topple the whole assemblage, make it difficult to believe that there was anything about the arrangement that could not have been built differently if the "right way" had not been shown boldly by Newcomen. As an assemblage of elements, some adopted but most adapted, the engine was a clear statement of the builder's personal style of invention.

The genius of James Watt was of a different kind, and to discuss the difference in terms of superiority smacks of useless historical partisanship. Newcomen selected the components of a steam engine and gave to each its proper place and function. Watt, on the other hand, originated at least two new major components, and in making a brilliant adaptation of a third he introduced the world to the notion of feedback for automatic control.

Watt began his work on steam engines in 1763, when, as an instrument maker at the University of Glasgow, he undertook the repair of a teaching model of



WATT ENGINE was depicted in this 1826 illustration. The engine transformed the vertical action of the piston rod *n* into rotary motion through the flywheel *Q*. Watt's special contributions included condenser *F*, parallel-motion linkage at left end of beam, centrifugal governor *Z* and "sun and planet" gear mechanism at center of flywheel, causing wheel to turn at double the speed of the engine.

a Newcomen engine. His careful and sustained study led him in 1765 to recognize that he might increase the thermal efficiency of the engine, as well as its capacity and operating speed, by condensing the steam in a chamber attached to, but separate from, the main steam cylinder. This was the first of his most important innovations.

His earliest patent, which included the separate condenser, was granted in 1769, but his first successful full-sized engine was not completed until 1775, the year in which Matthew Boulton became his partner. Parliament granted a patent extension to Watt that year, providing a virtual monopoly on the condensing steam engine for 25 years.

After Watt had devised a double-acting engine, in which steam moved the piston first in one direction and then in the other as it was admitted alternately to each end of the cylinder, the arch head and flat chain no longer sufficed to guide the upper end of the piston rod, because the chain transmitted force in tension only. Accordingly in 1783 Watt brought forth his second major innovation: the straight-line linkage that bears his name. Refining further his first ideas, Watt combined the straight-line linkage with a pantograph, a linkage system in parallelogram form, to produce the so-called "parallel motion" [*see bottom illustration on page 104*].

In these two inventions we find a measure of Watt's capacity: the separate condenser was neither anticipated nor invented independently by anyone else, and the parallel motion solved a problem whose existence was not even suspected until Watt overcame it. For the next 100 years mechanics and mathematicians occupied themselves in a search for alternative solutions.

Finally, in 1788 Watt adapted the centrifugal "flyball" governor to control the speed of his engine by linking the governor to the steam-inlet valve. The flyball governor had been used in grain mills to increase the distance between the flat grinding stones as their speed increased. Watt's use of the governor, however, added the far-reaching principle of feedback that made possible self-regulating, rather than merely automatic, machines. The ordinary steam engine and the Watt engine were built, in the words of Boulton, "with as great a difference of accuracy as there is between the blacksmith and the mathematical instrument maker." Thus the few astonishingly sophisticated Boulton and Watt engines in service toward the end of the century hurried a generation of machine builders to a higher order of accuracy, which in turn called for a whole new array of large, rugged and precise machine tools. The influence of the new tools on mechanization was profound and can be traced directly to the present. The effect of the separate condenser and self-regulating speed control on the direction of industrial technology can be appreciated if we recognize that their invention was an essential step toward the modern steam turbine. Undeniably Watt opened doors whose very existence might have gone unnoticed for 100 years after his time.

The Watt steam engine was twice as efficient, from the standpoint of fuel consumption, as even the best Newcomen engine. A recent study by two English economic historians, A. E. Musson of the University of Manchester and E. A. G. Robinson of the University of Cambridge, has shown, however, that both Savery and Newcomen engines were being built long after they had been

WORKING PUMP of Newcomen design is shown at a colliery in England. The pump was in use from 1791 until 1918. Subsequently it was taken down and re-erected at the Science Museum in London. Part of the working beam is visible below catwalk at top center.

made obsolete by Watt's improvements, and that Boulton and Watt supplied only about a third of all steam engines built during the 25-year period of the patent monopoly (1775–1800). It is also clear that a two-cylinder Newcomen engine capable of turning machinery was in existence, and that the high-pressure engines operating without condensers of any sort were soon to be built by Richard Trevithick in England and Oliver Evans in the U.S.

Since hindsight is one of our best-developed faculties, it has been possible for writers for more than 200 years to dismiss the appearance of the Newcomen engine of 1712 as well as the Watt engine of 1775–1788 as being merely normal responses to industrial demands. The well-established axiom of simultaneous but independent discovery, which can be interpreted to mean that a particular invention is inevitable, has been applied to suggest that if Thomas Newcomen had not built his engine, somebody else would have done so at about the same time.

This seems no more accurate in the case of Newcomen than in the case of Watt. In looking carefully at the Newcomen engine, it has become increasingly evident to me that it represents a unique solution to the problem the inventor set out to solve. There was no anticipation of the completed engine, and nobody came forward to contest Newcomen's priority of invention. The first radical modification occurred no sooner than 50 years later, when Watt conceived the separate condenser.

Newcomen was not the first man to "discover" the correct way to build a steam engine; there is no correct way. It is conceivable, for example, that he might have made the cylinder horizontal rather than vertical, that he might have supplied steam above atmospheric pressure (only eight pounds per square inch would have sufficed to do the work), or that he might have used a crank, connecting rod and flywheel. Any of these variations would have been possible if he had approached the problem differently. But by producing a machine that was a pumping engine, not easily adapted to the turning of wheels, Newcomen limited the options that lesser engineers could exploit in the future. He did the job his way, and he gave the world such a convincing statement of rightness in the machine he put together that he exerted an enormous influence on the direction in which English technology would proceed for the next several generations.