CHAPTER I

THE EARLY HISTORY OF THE STEAM-ENGINE

1. Heat-Engines in general. In the scientific treatment of the steam-engine we have in the first place, and mainly, to regard it as a heat-engine—that is, a machine in which heat is employed to do mechanical work. Other aspects of the steam-engine will present themselves when we come to examine the action of the mechanism in detail, but the foremost place must be given to thermodynamic considerations. From the thermodynamic point of view the function of a heat-engine is to get as much work as possible from a given supply of heat, or (to go a step further back) from the combustion of a given quantity of fuel. Hence a large part of our subject is the discussion of what is called the *efficiency* of the engine, which is the ratio of the work done to the heat supplied. We have to consider on what conditions efficiency depends, how its value is limited in theory and how nearly the limiting value may be attained in practice. We have to describe means of testing the efficiency of engines, and the results which such tests have given in actual cases. Much of what has to be said in regard to efficiency is applicable to all heat-engines, whatever be the character of the substance which is made use of as the means of doing work within the engine. In all practical heat-engines work is done through the expansion by heat of a fluid which exerts pressure and overcomes resistance as it expands. Thus in steam-engines the working substance is water and water-vapour, and work is done by the pressure which the substance exerts while its volume is undergoing change. This is true of engines of the turbine type as well as those in which the steam presses against a moving piston: in the former the work is done by setting in motion a part of the working substance itself, and causing its momentum to exert force upon a moving part of the machine. In air-engines the working substance is atmospheric air; in gas-engines and oil or petrol-engines it is a mixture of air with gas or with the vapour of an inflammable liquid and with gaseous products of combustion. Engines of this last type are called *internal-combustion* engines because the heat which it is the function of the engine to convert into power is developed by combustion within the working substance itself, instead of reaching the substance from an external source. Thus in an engine of the internal-combustion type the heat does not have to pass into the working substance by conduction through the wall of a containing vessel, such as a boiler, strong enough to bear the pressure of the fluid within. This secures advantages in respect of lightness and efficiency which have led to a greatly extended application of the internal-combustion principle, especially for small power installations and for the driving of road vehicles, aircraft, and ships. Notwithstanding, however, the multiplied use of internal-combustion engines during the first quarter of the twentieth century, and their recent application to the driving of large ships, the steam-engine (including, of course, its turbine form) continues to be the chief means of producing power on a large scale out of the potential energy of fuel.

As a preliminary to the study of the modern engine it will be useful to review, if only very briefly, some of the stages through which it has passed in its development. In any such historical sketch the largest share of attention necessarily falls to the work of Watt, whose inventions were as remarkable for their scientific interest as for their industrial importance. But it should be borne in mind that a process of evolution had been going on before the time of Watt which prepared the steam-engine for the immense improvements it received at his hands. The labours of Watt stand in a natural sequence to those of Newcomen, and Newcomen's to those of Papin and Savery. Savery's engine, again, was the reduction to practical form of a contrivance which had long before been known as a scientific toy.

2. Hero of Alexandria. The earliest notices of heat-engines are found in the *Pneumatics* of Hero of Alexandria, which dates from the second century before Christ. One of the contrivances mentioned there is the æolipile, a steam reaction-turbine consisting of a spherical vessel pivoted on a central axis and supplied with steam through one of the pivots. The steam escapes by bent pipes facing tangentially in opposite directions, at opposite ends of a diameter perpendicular to the axis. The globe revolves by reaction from the escaping steam, just as a Barker's mill is driven by escaping water. Another apparatus described by Hero (fig. 1)[1] is

[1] From Greenwood's translation of Hero's *Pneumatics*, edited by B. Woodcroft, 1851.

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interesting as the prototype of a class of engines which long afterwards became practically important. A hollow altar containing air is heated by a fire kindled on it; the air in expanding drives some of the water contained in a spherical vessel beneath the altar into a bucket, which descends and opens the temple doors above by pulling round a pair of vertical posts to which the doors are fixed. When the fire is extinguished the air cools, the water leaves the bucket, and the doors close. In another device a jet of water driven out by expanding air is turned to account as a fountain. Several other philosophical toys or pieces of conjuring apparatus of the like kind are also described, but there is no suggestion that the methods they illustrate could be applied on a large scale or turned to any useful account.

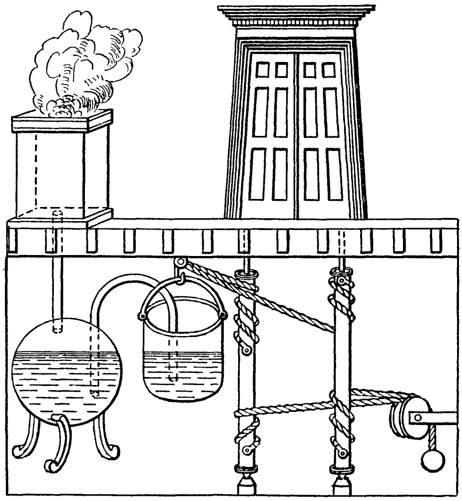
Fig. 1. Apparatus described by Hero.

3. Della Porta and De Caus. From the time of Hero to the seventeenth century there is no progress to record, though here and there we find evidence that appliances like those described by Hero were used for trivial purposes, such as organ-blowing and the turning of spits. The next distinct step was the publication in 1606 of a treatise on pneumatics by Giovanni Battista Della Porta, in which he shows an apparatus similar to Hero's fountain, but with steam instead of air as the displacing fluid. Steam generated in a separate vessel passed into a closed chamber containing water, and drove the water out through a pipe which opened near the bottom of the vessel. He also points out that the condensation of steam in the closed chamber may be used to produce a vacuum and suck up water from a lower level. In fact, his suggestions anticipate very fully the principle which a century later was applied by Savery in the earliest commercially successful steam-engine. In 1615 Salomon De Caus gives a plan of forcing up water by a steam-fountain which differs from Porta's only in having one vessel serve both as boiler and as displacement-chamber, the hot water being itself raised.

4. Branca's Steam Turbine. Another line of invention was taken by Giovanni Branca (1629), who designed an engine shaped like a water-wheel, to be driven by the impact of a jet of steam on its vanes, and, in its turn, to drive other mechanism for various useful purposes—what we should now call an impulse turbine. But Branca's suggestion was unproductive, and we find the course of invention revert to the line followed by Porta and De Caus.

5. Marquis of Worcester. The next contributor is one whose place is not easily assigned. To Edward Somerset, second marquis of Worcester, appears to be due the credit of proposing, if not of making, the first useful steam-engine. Its object was to raise water, and it worked probably like Porta's model, but with a pair of displacement-chambers, from each of which alternately water was forced by steam from an independent boiler, or perhaps by applying heat to the chamber itself, while the other vessel was allowed to refill. The only description of the engine is found in Art. 68 of Worcester's *Century of Inventions* (1663). There are no drawings, and the notice is so obscure that it is difficult to say whether there were any distinctly novel features except the double action. The inventor's account leaves much to the imagination. It is entitled "A Fire Water-work," and runs thus:—

An admirable and most forcible way to drive up water by fire, not by drawing or sucking it upwards, for that must be as the Philosopher calleth it, *Intra sphaeram activitatis*, which is but at such a distance. But this way hath no Bounder, if the Vessels be strong enough; for I have taken a piece of a whole Cannon, whereof the end was burst, and filled it three-quarters full of water, stopping and scruing up the broken end; as also the Touch-hole; and making a constant fire under it, within 24 hours it burst and made a great crack. So that having a way to make my Vessels, so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a constant Fountaine-stream forty foot high; one Vessel of water rarified by fire driveth up forty of cold water. And a man that tends the work is but to turn two Cocks, that one Vessel of water being consumed, another begins to force and re-fill with cold water, and so successively, the fire being tended and kept constant, which the self-same Person may likewise abundantly perform in the interim between the necessity of turning the said Cocks.

Later articles in the *Century of Inventions* contain notices of a device which, under the name of a "Water-commanding Engine," received protection by Act of Parliament and was experimented on by Worcester on a large scale at Vauxhall. But there is nothing to show distinctly that the Water-commanding Engine was a heat-engine at all, and the meagre accounts that have been given of it rather point to the conclusion that it was a form of "Perpetual Motion." In any case the experiments led to no practical result.

6. Savery. The steam-engine became commercially successful in the hands of Thomas Savery, who in 1698 obtained a patent for a water-raising engine, shown in fig. 2. Steam is admitted to one of the oval vessels *A*, displacing water, which it drives up through the check-valve *B*. When the vessel *A* is emptied of water, the supply of steam is stopped, and the steam already there is condensed by allowing a jet of cold water from a cistern above to stream over the outer surface of the vessel. This produces a vacuum and causes water to be sucked up through the pipe *C* and the valve *D*. Meanwhile, steam has been displacing water from the other vessel, and is ready to be condensed there. The valves *B* and *D* open only upwards. The supplementary boiler and furnace *E* are for feeding water to the main boiler; *E* is filled while cold and a fire is lighted under it; it then acts like the vessel of De Caus in forcing a supply of feed-water into the main boiler *F*. The gauge-cocks *G*, *G* for testing the level of the water in the boiler are an interesting feature of detail. Another form of Savery's engine had only one displacement-chamber and worked intermittently. In the use of

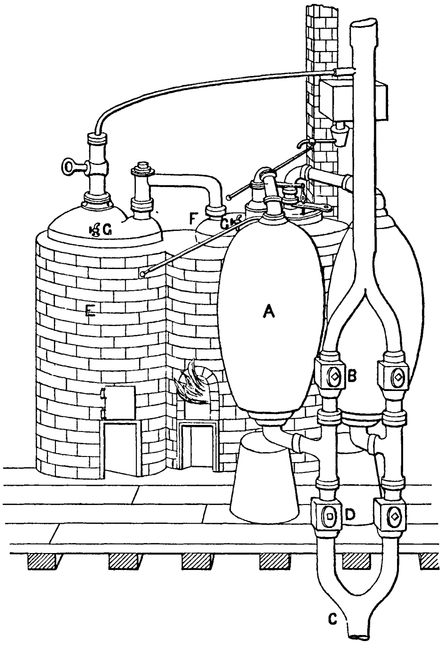

Fig. 2. Savery's Pumping Engine, 1698.

artificial means to condense the steam, and in the application of the vacuum so formed to raise water by suction from a level lower than that of the engine, the action used by Savery was probably an advance on that proposed or used by Worcester; in any case Savery's was the first engine to take a really practical shape. It found considerable employment in pumping mines and in raising water to supply houses and towns, and even to drive water-wheels. A serious difficulty which prevented its general use in mines was the fact that the height through which it would lift water was limited by the pressure the boiler and vessels could bear. Pressures as high as 8 or 10 atmospheres were employed—and that, too, without a safety-valve. But Savery found it no easy matter to deal with high-pressure steam; he complains that it melted his common solder, and forced him, as Desaguliers tells us, "to be at the pains and charge to have all his joints soldered with spelter." Apart from this drawback the waste of fuel was enormous, from the condensation of steam which took place on the surface of the water and on the sides of the displacement-chamber at each stroke; the consumption of coal was, in proportion to the work done, some twenty times greater than it is in a good modern steam-engine. In a tract called *The Miner's Friend*, Savery alludes thus to the alternate heating and cooling of the water-vessel: "On the outside of the vessel you may see how the water goes out as well as if the vessel were transparent, for so far as the steam continues within the vessel so far is the vessel dry without, and so very hot as scarce to endure the least touch of the hand. But as far as the water is, the said vessel will be cold and wet where any water has fallen on it; which cold and moisture vanishes as fast as the steam in its descent takes place of the water." Before Savery's engine was entirely displaced by its successor, Newcomen's, it was improved by Desaguliers, who applied to it the safety-valve (invented by Papin), and substituted condensation by a jet of cold water within the vessel for the surface condensation used by Savery.

To Savery is ascribed the first use of the familiar term "horse-power" as a measure of the performance of an engine.

7. Gunpowder Engines. Some twenty years before the date of Savery's patent, proposals had been made by several inventors to raise water by means of the explosive power of gunpowder.

One scheme was to explode the powder in a closed vessel furnished with valves which opened outwards and allowed a great part of the air and burnt gases to escape when the explosion took place. As the gas that remained became cool a partial vacuum was formed in the vessel, and this was used to draw up water from a lower level. It does not appear that these schemes were ever put in practice except experimentally. The most interesting of the gunpowder engines was that of Huygens (1680), who for the first time introduced the piston and cylinder as constituent parts of a heat-engine. In Huygens' engine the piston was set at the top of a vertical cylinder and a charge of powder was exploded below it. This expelled part of the gaseous contents through valves which opened outwards, and then the cooling of the remainder caused the piston to descend under atmospheric pressure. The piston in descending did work by raising a weight through the medium of a cord and pulley.

8. Papin. In 1690 Denis Papin, who ten years before had invented the safety-valve as an adjunct to his "digester," suggested that the condensation of steam should be employed to make a vacuum under a piston which had been previously raised by the expansion of the steam. Papin had been associated with Huygens in his experiments on the production of a vacuum under a piston by means of gunpowder, and had described Huygens' machine to the Royal Society. Noticing that after the explosion enough gas remained in the cylinder to fill about one-fifth of its volume, after cooling, he cast about for some means of obtaining a better vacuum. "By another way, therefore, I endeavoured to attain the same end, and since it is a property of water that a small quantity of it, converted into steam by heat, has an elastic force like that of air, but when cold supervenes, is again resolved into water so that no trace of the said elastic force remains, I saw that machines might be constructed wherein water, by means of no very intense heat and at small cost, might produce that perfect vacuum which had failed to be obtained by the use of gunpowder." He goes on to describe what was unquestionably the earliest cylinder and piston steam-engine, and his plan of using steam was that which afterwards took practical shape in the atmospheric engine of Newcomen. But his scheme was made unworkable by the fact that he proposed to use but one vessel as both boiler and cylinder. A small quantity of water was placed at the bottom of a cylinder and heat was applied. When the piston had risen the fire was removed, the steam was allowed to cool, and the piston did work in its down-stroke under the pressure of the atmosphere.

After hearing of Savery's engine in 1705 Papin turned his attention to improving it, and devised a modified form, shown in fig. 3, in which the displacement-chamber A was a cylinder, with a floating diaphragm or piston on the top of the water to keep the water and steam from direct contact with one another. The water was delivered into a closed air-vessel B, from which it issued in a continuous stream against the vanes of a water-wheel. After the steam had done its work in the displacement-chamber it was

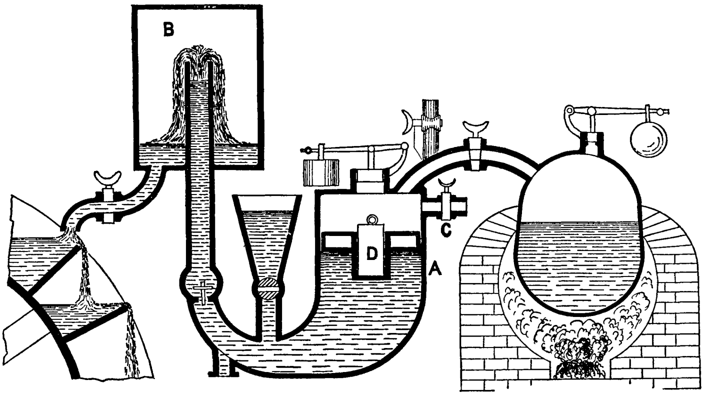

FIG. 3. Papin's modification of Savery's Engine, 1705.

allowed to escape by the stop-cock C instead of being condensed. This second engine of Papin's was in fact a non-condensing single-acting steam-pump, with steam-cylinder and pump-cylinder in one. A curious feature of it was the heater D, a mass of hot metal placed in the diaphragm for the purpose of keeping the steam dry. Among the many inventions of Papin was a boiler with an internal fire-box—the earliest example of a construction that is now almost universal[1].

9. Newcomen's "Atmospheric" Engine. While Papin was thus going back from his first notion of a piston engine to Savery's cruder type, a new inventor had appeared who made the piston

[1] For an account of Papin's inventions, see his *Life, and Correspondence with Leibnitz and Huygens*, by Dr E. Gerland, Berlin, 1881. See also Muirhead's *Life of Watt.*

engine a practical success by separating the boiler from the cylinder and by using (as Savery had done) artificial means to condense the steam. This was Newcomen, who in 1705, in conjunction with Savery and with Cawley, gave the steam-engine the form shown in fig. 4. The piston was connected by a chain with one end of an overhead beam. Steam admitted from the boiler to the cylinder allowed the piston to be raised by a heavy counterpoise hanging

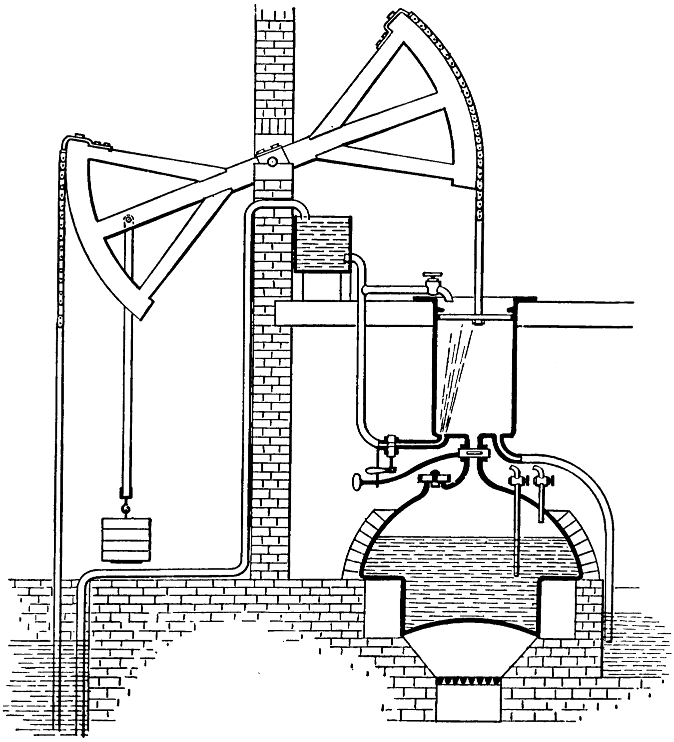

Fig. 4. Newcomen's Atmospheric Engine, 1705.

from the beam near the other end. Then the steam-valve was shut and a jet of cold water entered the cylinder and condensed the steam. The piston was consequently forced down by the pressure of the atmosphere and did work on the pump through the medium of a long rod which hung from the other end of the beam. The next entry of steam expelled the condensed water from the cylinder through an escape valve. The piston was kept tight by a layer of water on its upper surface. Condensation was at first effected by cooling the outside of the cylinder, but an accidental leakage of the packing water past the piston showed the advantage of condensing by a jet of injection water, and this plan took the place of surface condensation. The engine used steam which had a pressure little if at all greater than that of the atmosphere; sometimes indeed it was worked with the manhole-lid off the boiler. The function of the steam was merely to allow the piston to be raised, by making the pressure on the under side equal or nearly equal to the pressure on the top, and then to produce a vacuum by being condensed. Newcomen's engine was essentially the cylinder and piston of Papin combined with the separate boiler of Savery.

About 1711 Newcomen's engine began to be introduced for pumping mines. It is doubtful whether the engine was originally automatic in its action or depended on the periodical turning of taps by an attendant. An old print of an engine erected by Newcomen in 1712 near Dudley Castle shows a species of automatic gear. The common story is that in 1713 a boy named Humphrey Potter, whose duty it was to open and shut the valves of an engine he attended, made the engine self-acting by causing the beam itself to open and close the valves by means of cords and catches. This rude device was simplified in 1718 by Henry Beighton, who suspended from the beam a rod called the plug-tree, which worked the valves by means of tappets. By 1725 the engine was in common use in collieries, and it held its place without material change for about three-quarters of a century in all. Near the close of its career the atmospheric engine was much improved in its mechanical details by Smeaton, who built many large engines of this type about the year 1770, just after the great step which was to make Newcomen's engine obsolete had been taken by James Watt.

Like Savery's engine, Newcomen's was put to no other use than to pump water—in some instances for the purpose of turning water-wheels to drive other machinery. Compared with Savery's it had the great advantage that the intensity of pressure in the pump was not in any way limited by the pressure of the steam, but could be made as great as might be desired by reducing the area of the pump plunger. It shared with Savery's, in a scarcely less degree, the defect already pointed out, that steam was wasted by the alternate heating and cooling of the vessel into which it was led. Even contemporary writers complain of its "vast con-