A HISTORY

OF THE

GROWTH OF THE STEAM-ENGINE.

BY

ROBERT H. THURSTON, A.M., C.E.

PROFESSOR OF MECHANICAL ENGINEERING IN THE STEVENS INSTITUTE OF TECHNOLOGY, HOBOKEN, N. J.; MEMBER OF INSTITUTION OF ENGINEERS AND SHIPBUILDERS OF SCOTLAND, SOCIÉTÉ DES INGÉNIEURS CIVILS, VEREIN DEUTSCHE INGENIEURE, OESTERREICHISCHER INGENIEUR- UND ARCHITEKTEN-VEREIN; ASSOCIATE BRITISH INSTITUTION OF NAVAL ARCHITECTS, ETC. ETC.

THIRD EDITION.

LONDON:
KEGAN PAUL, TRENCH, & CO., 1 PATERNOSTER SQUARE.
1883.

PREFACE.

THIS little work embodies the more generally interesting portions of lectures first written for delivery at the STEVENS INSTITUTE OF TECHNOLOGY, in the winter of 1871–'72, to a mixed audience, composed, however, principally of engineers by profession, and of mechanics; it comprises, also, some material prepared for other occasions.

The author has consulted a large number of authors in the course of his work, and is very greatly indebted to several earlier writers. Of these, Stuart[1] is entitled to particular mention. His "History" is the earliest deserving the name; and his "Anecdotes" are of exceedingly great interest and of equally great historical value. The artistic and curious little sketches at the end of each chapter are from John Stuart, as are, usually, the drawings of the older forms of engines.

Greenwood's excellent translation of Hero, as edited by Bennett Woodcroft (London, 1851), can be consulted by those who are curious to learn more of that interesting old Greek treatise.

---

[1] "History of the Steam-Engine," London, 1824. "Anecdotes of the Steam-Engine," London, 1829.

Some valuable matter is from Farey,[1] who gives the most extended account extant of Newcomen's and Watt's engines. The reader who desires to know more of the life of Worcester, and more of the details of his work, will find in the very complete biography of Dircks[2] all that he can wish to learn of that great but unfortunate inventor. Smiles's admirably written biography of Watt[3] gives an equally interesting and complete account of the great mechanic and of his partners; and Muirhead[4] furnishes us with a still more detailed account of his inventions.

For an account of the life and work of John Elder, the great pioneer in the introduction of the now standard double-cylinder, or "compound," engine, the student can consult a little biographical sketch by Prof. Rankine, published soon after the death of Elder.

The only published sketch of the history of the science of thermo-dynamics, which plays so large a part of the philosophy of the steam-engine, is that of Prof. Tait—a most valuable monograph.

The section of this work which treats of the causes and the extent of losses of heat in the steam-engine, and of the methods available, or possibly available, to reduce the amount of this now immense waste of heat, is, in some

---

[1] "Treatise on the Steam-Engine," London, 1827.

[2] "Life, Times, and Scientific Labours of the Second Marquis of Worcester," London, 1865.

[3] "Lives of Boulton and Watt," London, 1865.

[4] "Life of James Watt," D. Appleton & Co., New York, 1859. "Mechanical Inventions of James Watt," London, 1854.

CHAPTER III.

THE DEVELOPMENT OF THE MODERN STEAM-ENGINE.

James Watt, his Birth and Parentage, 79; his Standing in School, 81; he learns his Trade in London, 81; Return to Scotland and Settlement in Glasgow, 82; the Newcomen Engine Model, 83; Discovery of Latent Heat, 84; Sources of Loss in the Newcomen Engine, 85; Facts experimentally determined by Watt, 86; Invention of the Separate Condenser, 87; the Steam-Jacket and other Improvements, 90; Connection with Dr. Roebuck, 91; Watt meets Boulton, 93; Matthew Boulton, 93; Boulton's Establishment at Soho, 95; the Partnership of Boulton and Watt, 97; the Kinneil Engine, 97; Watt's Patent of 1769, 98; Work of Boulton and Watt, 101; the Rotative Engine, 103; the Patent of 1781, 104; the Expansion of Steam—its Economy, 105; the Double-Acting Engine, 110; the "Compound" Engine, 110; the Steam-Hammer, 111; Parallel Motions, the Counter, 112; the Throttle-Valve and Governor, 114; Steam, Vacuum, and Water Gauges, 116; Boulton & Watt's Mill-Engine, 118; the Albion Mill and its Engine, 119; the Steam-Engine Indicator, 123; Watt in Social Life, 125; Discovery of the Composition of Water, 126; Death of James Watt, 128; Memorials and Souvenirs, 128.

William Murdoch and his Work, 132; Invention of Gas-Lighting, 134; Jonathan Hornblower and the Compound Engine, 135; Causes of the Failure of Hornblower, 137; William Bull and Richard Trevithick, 138; Edward Cartwright and his Engine, 140.

CHAPTER IV.

THE MODERN STEAM-ENGINE.

Introduction, 144; the Non-Condensing Engine and the Locomotive, 147; Newton's Locomotive, 1680, 149; Nathan Read's Steam-Carriage, 150; Cugnot's Steam-Carriage, 1769, 151; the Model Steam-Carriage of Watt and Murdoch, 1784, 153; Oliver Evans and his Plans, 1786, 153; Evans's Oruktor Amphibolis, 1804, 157; Richard Trevithick's Steam-Carriage, 1802, 159; Steam-Carriages of Griffiths and others, 160; Steam-Carriages of Goldsworthy Gurney, 1827, 161; Steam-Carriages of Walter Hancock, 1831, 165; Reports to the House of Commons, 1831, 170; the Introduction of the Railroad, 172; Richard Trevithick's Locomotives, 1804, 174; John Stevens and the Railroad, 1812, 178; William Hedley's Locomotives, 1813, 181; George Stephenson, 183; Stephenson's Killingworth Engine, 1813, 186; Stephenson's Second Locomotive, 1815, 187; Stephenson's Safety-Lamp, 1815, 187; Robert Stephenson & Co., 1824, 190; the Stockton & Darlington Engine, 1825, 191; the Liverpool & Manchester Railroad, 1826, 193; Trial of Competing Engines at Rainhill, 1829, 195; the Rocket and the Novelty, 198; Atmospheric Railways, 201; Character of George Ste-

CHAPTER V.

THE MODERN STEAM-ENGINE.

CHAPTER VI.

THE STEAM-ENGINE OF TO-DAY.

CHAPTER VII.

THE PHILOSOPHY OF THE STEAM-ENGINE.

CHAPTER VIII.

THE PHILOSOPHY OF THE STEAM-ENGINE.

PORTRAITS.

sel, *H*, over, in syphon-shape, to the bottom of a suspended bucket, *N X*. The suspending cord is carried over a pulley and led around two vertical barrels, *O P*, turning on pivots

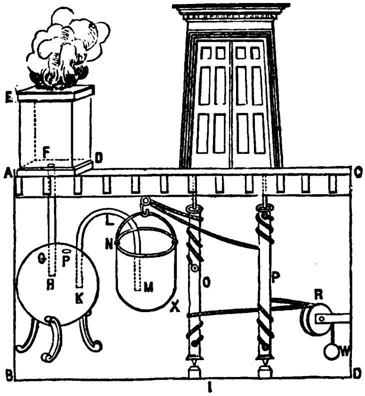


Fig. 1.—Opening Temple-Doors by Steam, B. C. 200.

at their feet, and carrying the doors above. Ropes led over a pulley, *R*, sustain a counterbalance, *W*.

On building a fire on the altar, the heated air within expands, passes through the pipe, *F G*, and drives the water contained in the vessel, *H*, through the syphon, *K L M*, into the bucket, *N X*. The weight of the bucket, which then descends, turns the barrels, *O P*, raises the counterbalance, and opens the doors of the temple. On extinguishing the fire, the air is condensed, the water returns through the syphon from the bucket to the sphere, the counterbalance falls, and the doors are closed.

Another contrivance is next described, in which the bucket is replaced by an air-tight bag, which, expanding as the heated air enters it, contracts vertically and actuates the mechanism, which in other respects is similar to that just described.

In these devices the spherical vessel is a perfect anticiwill be returned to the sphere from the pedestal. This can, evidently, only occur when the pipe *G* is closed previous to the commencement of this cooling. No such cock is mentioned, and it is not unlikely that the device only existed on paper.

Several steam-boilers are described, usually simple pipes or cylindrical vessels, and the steam generated in them by the heat of the fire on the altar forms a steam-blast. This blast is either directed into the fire, or it "makes a blackbird sing," blows a horn for a triton, or does other equally useless work. In one device, No. 70, the steam issues from a reaction-wheel revolving in the horizontal plane, and causes dancing images to circle about the altar. A more mechanical and more generally-known form of this device is that which is frequently described as the "First Steam Engine." The sketch from Stuart is similar in general form, but more elaborate in detail, than that copied by Greenwood, which is here also reproduced, as representing more accurately the simple form which the mechanism of the "Æolipile," or Ball of Æolus, assumed in those early times.

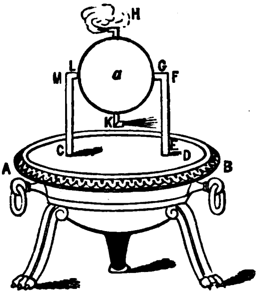


FIG. 3.—Hero's Engine, B. C. 200.

The cauldron, *A B*, contains water, and is covered by the steam-tight cover, *C D*. A globe is supported above the cauldron by a pair of tubes, terminating, the one, *C M*, in a posed an essential change in this succession, which begins with Hero, and which did not end with Watt.

The use of steam in Hero's fountain was as necessary a step as, although less striking than, any of the subsequent modifications of the machine. In Porta's contrivance, too, we should note particularly the separation of the boiler from the "forcing vessel"—a plan often claimed as original with later inventors, and as constituting a fair ground for special distinction.

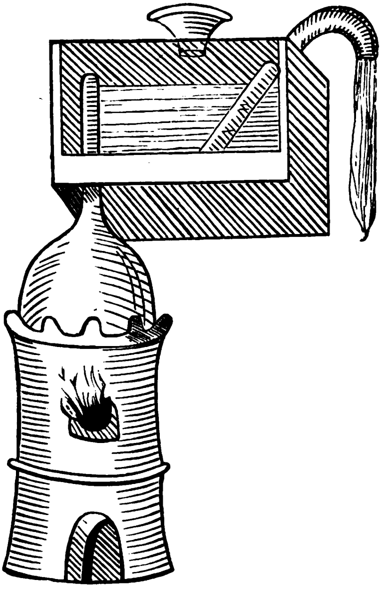


FIG. 4.—Porta's Apparatus, A. D. 1601.

The rude engraving (Fig. 4) above is copied from the book of Porta, and shows plainly the boiler mounted above a furnace, from the door of which the flame is seen issuing, and above is the tank containing water. The opening in the top is closed by the plug, as shown, and the steam issuing from the boiler into the tank near the top, the water is driven out through the pipe at the left, leading up from the bottom of the tank.

Florence Rivault, a Gentleman of the Bedchamber to

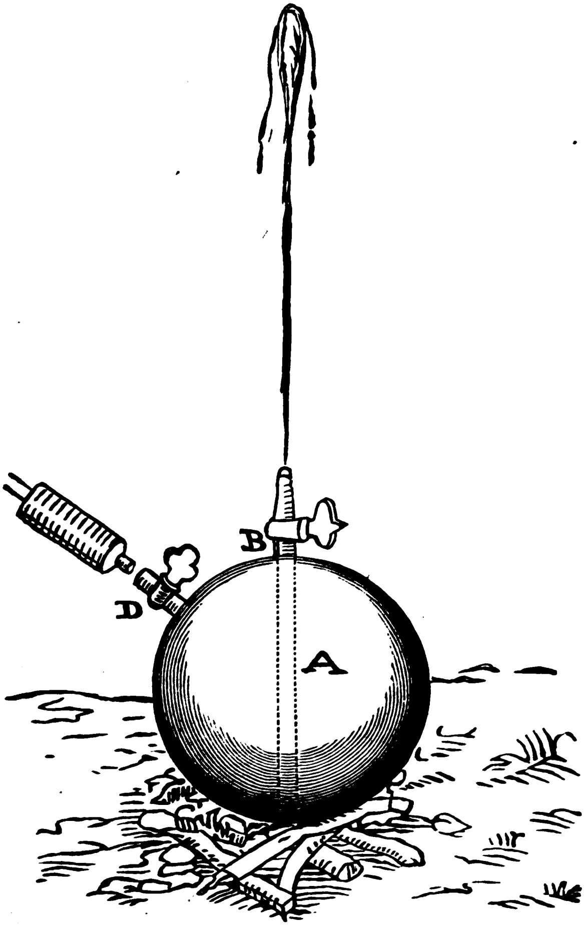


Fig. 5.—De Caus's Apparatus, A. D. 1605.

the use of steam in the arts which has been found in English literature. The patentee held his grant fourteen years, on condition of paying an annual fee of £3 6*s*. 8*d*. to the Crown.

The second claim is distinct as an application of steam, the language being that which was then, and for a century and a half subsequently, always employed in speaking of its use. The steam-engine, in all its forms, was at that time known as the "fire-engine." It would seem not at all improbable that the third, fifth, and seventh claims are also applications of steam-power.

Thomas Grant, in 1632, and Edward Ford, in 1640, also patented schemes, which have not been described in detail, for moving ships against wind and tide by some new and great force.

Dr. John Wilkins, Bishop of Chester, an eccentric but learned and acute scholar, described, in 1648, Cardan's smoke-jack, the earlier æolipiles, and the power of the confined steam, and suggested, in a humourous discourse, what he thought to be perfectly feasible—the construction of a flying-machine. He says: "Might not a 'high pressure' be applied with advantage to move wings as large as those of the 'ruck's' or the 'chariot'? The engineer might probably find a corner that would do for a coal-station near some of the 'castles'" (castles in the air). The reverend wit proposed the application of the smoke-jack to the chiming of bells, the reeling of yarn, and to rocking the cradle.

Bishop Wilkins writes, in 1648 ("Mathematical Magic"), of æolipiles as familiar and useful pieces of apparatus, and describes them as consisting "of some such material as may endure the fire, having a small hole at which they are filled with water, and out of which (when the vessels are heated) the air doth issue forth with a strong and lasting violence." "They are," the bishop adds, "frequently used for the exciting and contracting of heat in the melting of glasses or metals. They may also be contrived to be serviceable for sundry other pleasant uses, as for the moving of sails in a chimney-corner, the motion of which sails may be applied to the turning of a spit, or the like."

Kircher gives an engraving ("Mundus Subterraneus") showing the last-named application of the æolipile; and Erckern ("Aula Subterranea," 1672) gives a picture illustrating their application to the production of a blast in smelting ores. They seem to have been frequently used, and in all parts of Europe, during the seventeenth century, for blowing fires in houses, as well as in the practical work of the various trades, and for improving the draft of chimneys. The latter application is revived very frequently by the modern inventor.

SECTION II. — THE PERIOD OF APPLICATION—WORCESTER, PAPIN, AND SAVERY.

We next meet with the first instance in which the expansive force of steam is supposed to have actually been applied to do important and useful work.

In 1663, Edward Somerset, second Marquis of Worcester, published a curious collection of descriptions of his inventions, couched in obscure and singular language, and called "A Century of the Names and Scantlings of Inventions by me already Practised."

One of these inventions is an apparatus for raising water by steam. The description was not accompanied by a drawing, but the sketch here given (Fig. 7) is thought probably to resemble one of his earlier contrivances very closely.

Steam is generated in the boiler *a*, and thence is led into the vessel *e*, already nearly filled with water, and fitted up like the apparatus of De Caus. It drives the water in a jet out through the pipe *f*. The vessel *e* is then shut off from the boiler *a*, is again filled through the pipe *h*, and the operthe boiler being admitted to each vessel, *A* and *A′*, alternately, and there condensing, the vacuum formed permits the pressure of the atmosphere to force the water from the well through the pipes, *G* and *G′*. While one is filling, the steam is forcing the charge of water from the other up the discharge-pipe, *E*. As soon as each is emptied, the steam is shut off from it and turned into the other, and the condensation of the steam remaining in the vessel permits it to fill again. As will be seen presently, this is substantially, and almost precisely, the form of engine of which the invention is usually attributed to Savery, a later inventor.

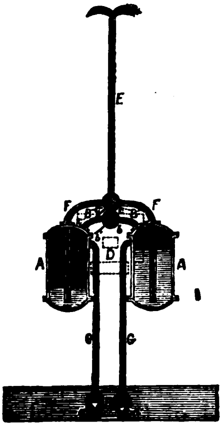


Fig. 8.—Worcester's Engine, A. D. 1665.

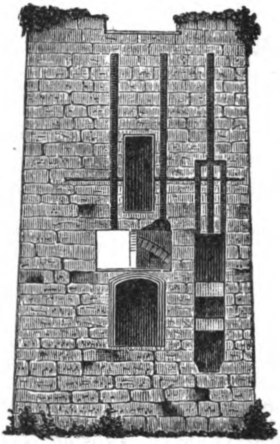


Fig. 9.—Wall of Raglan Castle.

Worcester never succeeded in forming the great company which he hoped would introduce his invention on a scale commensurate with its importance, and his fate was that of nearly all inventors. He died poor and unsuccessful.

His widow, who lived until 1681, seemed to have become as confident as was Worcester himself that the invention had value, and, long after his death, was still endeavrecorded plan, probably, for surface-condensation and complete retention of the working-fluid. He proposed a gunpowder-engine, of which[1] he described three varieties.

In one of these engines he displaced the atmosphere by the gases produced by the explosion, and the vacuum thus obtained was utilized in raising water by the pressure of the air. In the second machine, the pressure of the gases evolved by the combustion of the powder acted directly upon the water, forcing it upward; and in the third design, the pressure of the vapour drove a piston, and this engine was described as fitted to supply power for many purposes. There is no evidence that he constructed these machines, however, and they are here referred to simply as indicating that all the elements of the machine were becoming well known, and that an ingenious mechanic, combining known devices, could at this time have produced the steam-engine. Its early appearance should evidently have been anticipated.

Hautefeuille, if we may judge from evidence at hand, was the first to propose the use of a piston in a heat-engine, and his gunpowder-engine seems to have been the first machine which would be called a heat-engine by the modern mechanic. The earlier "machines" or "engines," including that of Hero and those of the Marquis of Worcester, would rather be denominated "apparatus," as that term is used by the physicist or the chemist, than a machine or an engine, as the terms are used by the engineer.

Huyghens, in 1680, in a memoir presented to the Academy of Sciences, speaks of the expansive force of gunpowder as capable of utilization as a convenient and portable mechanical power, and indicates that he had designed a machine in which it could be applied.

This machine of Huyghens is of great interest, not sim-

---

[1] "Pendule Perpetuelle, avec la manière d'éléver d'eau par le moyen de la poudre à canon." Paris, 1678.

ply because it was the first gas-engine and the prototype of the very successful modern explosive gas-engine of Otto and Langen, but principally as having been the first engine which consisted of a cylinder and piston. The sketch shows its form. It consisted of a cylinder, *A*, a piston, *B*, two relief-pipes, *C C*, fitted with check-valves and a system of pulleys, *F*, by which the weight is raised. The explosion of the powder at *H* expels the air from the cylinder. When the products of combustion have cooled, the pressure of the atmosphere is no longer counterbalanced by that of air beneath, and the piston is forced down, raising the weight. The plan was never put in practice, although the invention was capable of being made a working and possibly useful machine.

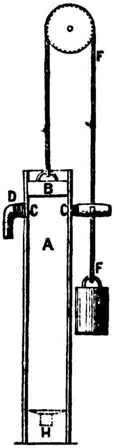


FIG. 10.—Huyghens's Engine, 1680.

At about this period the English attained some superiority over their neighbours on the Continent in the practical application of science and the development of the useful arts, and it has never since been lost. A sudden and great development of applied science and of the useful arts took place during the reign of Charles II., which is probably largely attributable to the interest taken by that monarch in many branches of construction and of science. He is said to have been very fond of mathematics, mechanics, chemistry, and natural history, and to have had a laboratory erected, and to have employed learned men to carry on experiments and lines of research for his satisfaction. He was especially fond of the study and investigation of the arts and sciences most closely related to naval architecture and navigation, and devoted much attention to the determination of the best forms of vessels, and to the discovery of the best kinds of ship-timber. His brother, the Duke of York, was equally fond of this study, and was his companion in some of his work.

Great as is the influence of the monarch, to-day, in forming the tastes and habits and in determining the direction of the studies and labours of the people, his influence was vastly more potent in those earlier days; and it may well be believed that the rapid strides taken by Great Britain from that time were, in great degree, a consequence of the well-known habits of Charles II., and that the nation, which had an exceptional natural aptitude for mechanical pursuits, should have been prompted by the example of its king to enter upon such a course as resulted in the early attainment of an advanced position in all branches of applied science.

The appointment, under Sir Robert Moray, the superintendent of the laboratory of the king, of Master Mechanic, was conferred upon Sir Samuel Morland, a nobleman who, in his practical knowledge of mechanics and in his ingenuity and fruitfulness of invention, was apparently almost equal to Worcester. He was the son of a Berkshire clergyman, was educated at Cambridge, where he studied mathematics with great interest, and entered public life soon after. He served the Parliament under Cromwell, and afterward went to Geneva. He was of a decidedly literary turn of mind, and wrote a history of the Piedmont churches, which gave him great repute with the Protestant party. He was induced subsequently, on the accession of Charles II., to take service under that monarch, whose gratitude he had earned by revealing a plot for his assassination.

He received his appointment and a baronetcy in 1660, and immediately commenced making experiments, partly at his own expense and partly at the cost of the royal exchequer, which were usually not at all remunerative. He built hand fire-engines of various kinds, taking patents on them, which brought him as small profits as did his work for the king, and invented the speaking-trumpet, calculating machines, and a capstan. His house at Vauxhall was full of curious devices, the products of his own ingenuity.

He devoted much attention to apparatus for raising water. His devices seem to have usually been modifications of the now familiar force-pump. They attracted much attention, and exhibitions were made of them before the king and queen and the court. He was sent to France on business relating to water-works erected for King Charles, and while in Paris he constructed pumps and pumping apparatus for the satisfaction of Louis XIV. In his book,[1] published in Paris in 1683, and presented to the king, and an earlier manuscript,[2] still preserved in the British Museum, Morland shows a perfect familiarity with the power of steam. He says, in the latter: "Water being evaporated by fire, the vapours require a greater space (about two thousand times) than that occupied by the water; and, rather than submit to imprisonment, it will burst a piece of ordnance. But, being controlled according to the laws of statics, and, by science, reduced to the measure of weight and balance, it bears its burden peaceably (like good horses), and thus may be of great use to mankind, especially for the raising of water, according to the following table, which indicates the number of pounds which may be raised six inches, 1,800 times an hour, by cylinders half-filled with water, and of the several diameters and depths of said cylinders."

He then gives the following table, a comparison of which with modern tables proves Morland to have acquired a very considerable and tolerably accurate knowledge of the volume and pressure of saturated steam:

---

[1] "Elevation des Eaux par toute sorte de Machines réduite à la Mesure au Poids et à la Balance, présentée a Sa Majesté Très Chrétienne, par le Chevalier Morland, Gentilhomme Ordinaire de la Chambre Privée et Maistre de Mechaniques du Roy de la Grande Bretagne, 1683."

[2] "Les Principes de la Nouvelle Force de Feu, inventée par le Chevalier Morland, l'an 1682, et présentée a Sa Majesté Très Chrétienne, 1683."

	Cylinders.		Pounds.
	Diameter in Feet.	Depth in Feet.	Weight to be Raised.
	1	2	15
	2	4	120
	3	6	405
	4	8	960
	5	10	1,876
	6	10	3,240
Number of cylinders having a diameter of 6 feet and a depth of 12 feet.	1	12	3,240
	2	12	6,480
	3	12	9,720
	4	12	12,960
	5	12	16,200
	6	12	19,440
	7	12	22,680
	8	12	25,920
	9	12	29,190
	10	12	32,400
	20	12	64,800
	30	12	97,200
	40	12	129,600
	50	12	162,000
	60	12	194,400
	70	12	226,800
	80	12	259,200
	90	12	291,600

The rate of enlargement of volume in the conversion of water into steam, as given in Morland's book, appears remarkably accurate when compared with statements made by other early experimenters. Desaguliers gave the ratio of volumes at 14,000, and this was accepted as correct for many years, and until Watt's experiments, which were quoted by Dr. Robison as giving the ratio at between 1,800 and 1,900. Morland also states the "duty" of his engines in the same manner in which it is stated by engineers to-day.

Morland must undoubtedly have been acquainted with the work of his distinguished contemporary, Lord Worcester, and his apparatus seems most likely to have been a modification—perhaps improvement—of Worcester's engine. His house was at Vauxhall, and the establishment set up for the king was in the neighbourhood. It may be that Morland is to be credited with greater success in the introduction of his predecessor's apparatus than the inventor himself.

Dr. Hutton considered this book to have been the earliest account of the steam-engine, and accepts the date—1682—as that of the invention, and adds, that "the project seems to have remained obscure in both countries till 1699, when Savery, who probably knew more of Morland's invention than he owned, obtained a patent," etc. We have, however, scarcely more complete or accurate knowledge of the extent of Morland's work, and of its real value, than of that of Worcester. Morland died in 1696, at Hammersmith, not far from London, and his body lies in Fulham church.

From this time forward the minds of many mechanicians were earnestly at work on this problem—the raising of water by aid of steam. Hitherto, although many ingenious toys, embodying the principles of the steam-engine separately, and sometimes to a certain extent collectively, had been proposed, and even occasionally constructed, the world was only just ready to profit by the labours of inventors in this direction.

But, at the end of the seventeenth century, English miners were beginning to find the greatest difficulty in clearing their shafts of the vast quantities of water which they were meeting at the considerable depths to which they had penetrated, and it had become a matter of vital importance to them to find a more powerful aid in that work than was then available. They were, therefore, by their necessities stimulated to watch for, and to be prepared promptly to take advantage of, such an invention when it should be offered them.

The experiments of Papin, and the practical application of known principles by Savery, placed the needed apparatus in their hands.

but met with no success. The principal objector was the Surveyor of the Navy, who dismissed Savery, with a remark which illustrates a spirit which, although not yet extinct, is less frequently met with in the public service now than then: "What have interloping people, that have no concern with us, to do to pretend to contrive or invent things for us?"[1] Savery then fitted his apparatus into a small vessel, and exhibited its operation on the Thames. The invention was never introduced into the navy, however.

It was after this time that Savery became the inventor of a steam-engine. It is not known whether he was familiar with the work of Worcester, and of earlier inventors. Desaguliers[2] states that he nad read the book of Worcester, and that he subsequently endeavoured to destroy all evidence of the anticipation of his own invention by the marquis by buying up all copies of the century that he could find, and burning them. The story is scarcely credible. A comparison of the drawings given of the two engines exhibits, nevertheless, a striking resemblance; and, assuming that of the marquis's engine to be correct, Savery is to be given credit for the finally successful introduction of the "semi-omnipotent" "water-commanding" engine of Worcester.

The most important advance in actual construction, therefore, was made by Thomas Savery. The constant and embarrassing expense, and the engineering difficulties presented by the necessity of keeping the British mines, and particularly the deep pits of Cornwall, free from water, and the failure of every attempt previously made to provide effective and economical pumping-machinery, were noted by Savery, who, July 25, 1698, patented the design of the first engine which was ever actually employed in this work. A working-model was submitted to the Royal Society of Lon-

---

[1] "Navigation Improved; or, The Art of Rowing Ships of all rates in Calms, with a more Easy, Swift, and Steady Motion, than Oars can," etc., etc. By Thomas Savery, Gent. London, 1698.

[2] "Experimental Philosophy," vol. ii., p. 465.

pipes, *C C*, with two copper receivers, *D D*. There were led from the bottom of these receivers branch pipes, *F F*, which turned upward, and were united to form a rising main, or "forcing-pipe," *G*. From the top of each receiver was led a pipe, which was turned downward, and these pipes united to form a suction-pipe, which was led down to the bottom of the well or reservoir from which the water was to be drawn. The maximum lift allowable was stated at 24 feet.

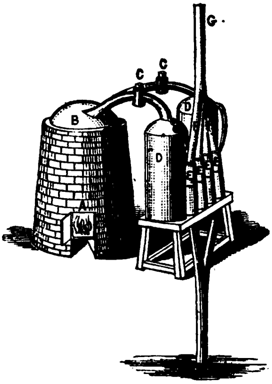


FIG. 11.—Savery's Model, 1698.

The engine was worked as follows : Steam is raised in the boiler, *B*, and a cock, *C*, being opened, a receiver, *D*, is filled with steam. Closing the cock, *C*, the steam condensing in the receiver, a vacuum is created, and the pressure of the atmosphere forces the water up, through the supply-pipe, from the well into the receiver. Opening the cock, *C*, again, the check-valve in the suction-pipe at *E* closes, the steam drives the water out through the forcing-pipe, *G*, the clack-valve, *E*, on that pipe opening before it, and the liquid is expelled from the top of the pipe. The valve, *C*, is again closed ; the steam again condenses, and the engine is worked as before. While one of the two receivers is discharging, the other is filling, as in the machine of the Marquis of Worcester, and thus the steam is drawn from the boiler with tolerable regularity, and the expulsion of water takes place with similar uniformity, the two systems of receivers and pipes being worked alternately by the single boiler.

In another and still simpler little machine,[1] which he

---

[1] Bradley, "New Improvements of Planting and Gardening." Switzer, "Hydrostatics," 1729.

erected at Kensington (Fig. 12), the same general plan was adopted, combining a suction-pipe, *A*, 16 feet long and 3 inches in diameter; a single receiver, *B*, capable of containing 13 gallons; a boiler, *C*, of about 40 gallons capacity; a forcing-pipe, *D*, 42 feet high, with the connecting pipe and cocks, *E F G;* and the method of operation was as already described, except that *surface-condensation* was employed, the cock, *F*, being arranged to shower water from the rising main over the receiver, as shown. Of the first engine Switzer says: "I have heard him say myself, that the very first time he played, it was in a potter's house at Lambeth, where, though it was a small engine, yet it (the water) forced its way through the roof, and struck off the tiles in a manner that surprised all the spectators."

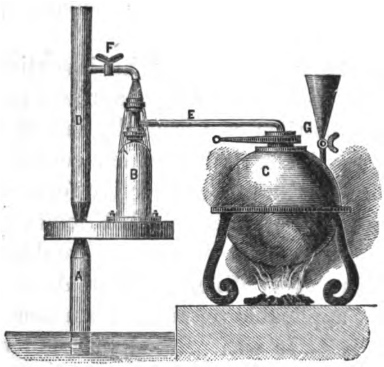


FIG. 12.—Savery's Engine, 1698.

The Kensington engine cost £50, and raised 3,000 gallons per hour, filling the receiver four times a minute, and required a bushel of coal per day. Switzer remarks: "It must be noted that this engine is but a small one in comparison with many others that are made for coal-works; but this is sufficient for any reasonable family, and other

The charge of water is driven out through the lower pipe and the cock *R*, and up the pipe *S* as before, while the other vessel is refilling preparatory to acting in its turn.

The two vessels are thus alternately charged and discharged, as long as is necessary.

Savery's method of supplying his boiler with water was at once simple and ingenious.

The small boiler, *D*, is filled with water from any convenient source, as from the stand-pipe, *S*. A fire is then built under it, and, when the pressure of steam in *D* becomes greater than in the main boiler, *L*, a communication is opened between their lower ends, and the water passes, under pressure, from the smaller to the larger boiler, which is thus "fed" without interrupting the work. *G* and *N* are *gauge-cocks*, by which the height of water in the boilers is determined; they were first adopted by Savery.

Here we find, therefore, the first really practicable and commercially valuable steam-engine. Thomas Savery is entitled to the credit of having been the first to introduce a machine in which the power of heat, acting through the medium of steam, was rendered generally useful.

It will be noticed that Savery, like the Marquis of Worcester, used a boiler separate from the water-reservoir.

He added to the "water-commanding engine" of the marquis the system of *surface-condensation*, by which he was enabled to charge his vessels when it became necessary to refill them; and added, also, the secondary boiler, which enabled him to supply the working-boiler with water without interrupting its work.

The machine was thus made capable of working uninterruptedly for a period of time only limited by its own decay.

Savery never fitted his boilers with safety-valves, although it was done later by others; and in deep mines he was compelled to make use of higher pressures than his rudely-constructed boilers could safely bear.

Savery's engine was used at a number of mines, and

Savery proposed to use his engine for driving mills; but there is no evidence that he actually made such an application of the machine, although it was afterward so applied by others. The engine was not well adapted to the drainage of surface-land, as the elevation of large quantities of water through small heights required great capacity of receivers, or compelled the use of several engines for each case. The filling of the receivers, in such cases, also compelled the heating of large areas of cold and wet metallic surfaces by the steam at each operation, and thus made the work comparatively wasteful of fuel. Where used in mines, they were necessarily placed within 30 feet or less of the lowest level, and were therefore exposed to danger of submergence whenever, by any accident, the water should rise above that level. In many cases this would result in the loss of the engine, and the mine would remain "drowned," unless another engine should be procured to pump it out. Where the mine was deep, the water was forced by the pressure of steam from the level of the engine-station to the top of the lift. This compelled the use of pressures of several atmospheres in many cases; and a pressure of three atmospheres, or about 45 pounds per square inch, was considered, in those days, as about the maximum pressure allowable. This difficulty was met by setting a separate engine at every 60 or 80 feet, and pumping the water from one to the other. If any one engine in the set became disabled, the pumping was interrupted until that one machine could be repaired. The size of Savery's largest boilers was not great, their maximum diameter not exceeding two and a half feet. This made it necessary to provide several of his engines, usually, for a single mine, and at each level. The first cost and the expense of repairs were exceedingly serious items. The expense and danger, either real or apparent, were thus sufficient to deter many from their use, and the old method of raising water by horse-power was adhered to.

rapidity of condensation, but enabling the designer to employ a comparatively small receiver or condenser.

The engine is shown in Fig. 15, which is copied from the "Experimental Philosophy" of Desaguliers.

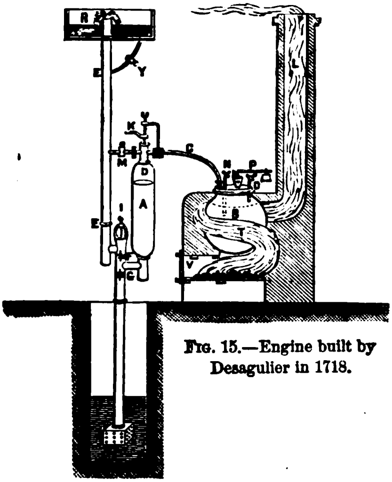


Fig. 15.—Engine built by Desagulier in 1718.

The receiver, *A*, is connected to the boiler, *B*, by a steam-pipe, *C*, terminating at the two-way cock, *D*; the "forcing-pipe," *E*, has at its foot a check-valve, *F*, and the valve *G* is a similar check at the head of the suction-pipe. *H* is a strainer, to prevent the ingress of chips or other bodies carried to the pipe by the current; the cap above the valves is secured by a bridle, or stirrup, and screw, *I*, and may be readily removed to clear the valves or to renew them; *K* is the handle of the two-way cock; *M* is the injection-cock, and is kept open during the working of the engine; *L* is the chimney-flue; *N* and *O* are gauge-cocks fitted to pipes leading to the proper depths within the boiler, the water-line being somewhere between the levels of their lower ends; *P* is a lever safety-valve, as first used on the

"Digester" of Papin; *R* is the reservoir into which the water is pumped; *T* is the flue, leading spirally about the boiler from the furnace, *V*, to the chimney; *Y* is a cock fitted in a pipe through which the rising-main may be filled from the reservoir, should injection-water be needed when that pipe is empty.

Seven of these engines were built, the first of which was made for the Czar of Russia. Its boiler had a capacity of "five or six hogsheads," and the receiver, "holding one hogshead," was filled and emptied four times a minute. The water was raised "by suction" 29 feet, and forced by steam pressure 11 feet higher.

Another engine built at about this time, to raise water 29 feet "by suction," and to force it 24 feet higher, made 6 "strokes" per minute, and, when forcing water but 6 or 8 feet, made 8 or 9 strokes per minute. Twenty-five years later a workman overloaded the safety-valve of this engine, by placing the weight at the end and then adding "a very heavy plumber's iron." The boiler exploded, killing the attendant.

Desagulier says that one of these engines, capable of raising ten tons an hour 38 feet, in 1728 or 1729, cost £80, exclusive of the piping.

Blakely, in 1766, patented an improved Savery engine, in which he endeavoured to avoid the serious loss due to condensation of the steam by direct contact with the water, by interposing a cushion of oil, which floated upon the water and prevented the contact of the steam with the surface of the water beneath it. He also used air for the same purpose, sometimes in double receivers, one supported on the other. These plans did not, however, prove satisfactory.

Rigley, of Manchester, England, soon after erected Savery engines, and applied them to the driving of mills, by pumping water into reservoirs, from whence it returned to the wells or ponds from which it had been raised, turning water-wheels as it descended.

strokes a minute; the later and improved engines made 10 or 12.

The steam-engine has now assumed a form that somewhat resembles the modern machine.

The Newcomen engine is seen at a glance to have been a combination of earlier ideas. It was the engine of Huyghens, with its cylinder and piston as improved by Papin, by the substitution of steam for the gases generated by the explosion of gunpowder; still further improved by Newcomen and Calley by the addition of the method of condensation used in the Savery engine. It was further modified, with the object of applying it directly to the working of the pumps of the mines by the introduction of the overhead beam, from which the piston was suspended at one end and the pump-rod at the other.

The advantages secured by this combination of inventions were many and manifest. The piston not only gave economy by interposing itself between the impelling and the resisting fluid, but, by affording opportunity to make the area of piston as large as desired, it enabled Newcomen to use any convenient pressure and any desired proportions for any proposed lift. The removal of the water to be lifted from the steam-engine proper and handling it with pumps, was an evident cause of very great economy of steam.

The disposal of the water to be raised in this way also permitted the operations of condensation of steam, and the renewal of pressure on the piston, to be made to succeed each other with rapidity, and enabled the inventor to choose, unhampered, the device for securing promptly the action of condensation.

Desaguliers, in his account of the introduction of the engine of Newcomen, says that, with his coadjutor Calley, he "made several experiments in private about the year 1710, and in the latter end of the year 1711 made proposals to drain the water of a colliery at Griff, in Warwickshire, eter, and the flow of water is regulated by the injection-cock, *r*. The cap at the end, *d*, is pierced with several holes, and the stream thus divided rises in jets when admitted, and, striking the lower side of the piston, the spray thus produced very rapidly condenses the steam, and produces a vacuum beneath the piston. The valve, *e*, on the upper end of the injection-pipe, is a check-valve, to prevent leakage into the engine when the latter is not in operation. The little pipe, *f*, supplies water to the upper side of the piston, and, keeping it flooded, prevents the entrance of air when the packing is not perfectly tight.

The "working-plug," or plug-rod, *Q*, is a piece of timber slit vertically, and carrying pins which engage the handles of the valves, opening and closing them at the proper times. The steam-cock, or regulator, has a handle, *h*, by which it is moved. The iron rod, *i i*, or spanner, gives motion to the handle, *h*.

The vibrating lever, *k l*, called the *Y*, or the "tumbling-bob," moves on the pins, *m n*, and is worked by the levers, *o p*, which in turn are moved by the plug-tree. When *o* is depressed, the loaded end, *k*, is given the position seen in the sketch, and the leg *l* of the *Y* strikes the spanner, *i i*, and, opening the steam-valve, the piston at once rises as steam enters the cylinder, until another pin on the plug-rod raises the piece, *P*, and closes the regulator again. The lever, *q r*, connects with the injection-cock, and is moved, when, as the piston rises, the end, *q*, is struck by a pin on the plug-rod, and the cock is opened and a vacuum produced. The cock is closed on the descent of the plug-tree with the piston. An eduction-pipe, *R*, fitted with a clock, conveys away the water in the cylinder at the end of each down-stroke; the water thus removed is collected in the hot-well, *S*, and is used as feed-water for the boiler, to which it is conveyed by the pipe *T*. At each down-stroke, while the water passes out through *R*, the air which may have collected in the cylinder is driven out through the "snifting-valve," *s*. The steam-cylinder is supported on strong beams, *t t*; it has around its upper edge a guard, *v*, of lead, which prevents the overflow of the water on the top of the piston. The excess of this water flows away to the hot-well through the pipe *W*.

Catch-pins, *x*, are provided, to prevent the beam descending too far should the engine make too long a stroke; two wooden springs, *y y*, receive the blow. The great beam is carried on sectors, *z z*, to diminish losses by friction.

The boilers of Newcomen's earlier engines were made of copper where in contact with the products of combustion, and their upper parts were of lead. Subsequently, sheet-iron was substituted. The steam-space in the boiler was made of 8 or 10 times the capacity of the cylinder of the engine. Even in Smeaton's time, a chimney-damper was not used, and the supply of steam was consequently very variable. In the earlier engines, the cylinder was placed on the boiler; afterward, they were placed separately, and supported on a foundation of masonry. The injection or "jack-head" cistern was placed from 12 to 30 feet above the engine, the velocity due the greater altitude being found to give the most perfect distribution of the water and the promptest condensation.

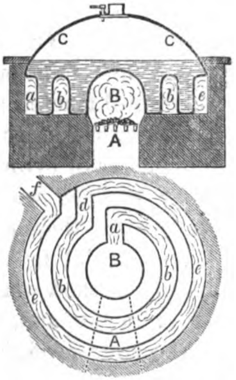


FIG. 22.—Boiler of Newcomen's Engine, 1763.

Smeaton covered the lower side of his steam-pistons with wooden plank about 2¼ inches thick, in order that it should absorb and waste less heat than when the iron was directly exposed to the steam. Mr. Beighton was the first to use the water of condensation for feeding the boiler, taking it directly from the eduction-pipe, or the "hot-well." Where only a sufficient amount of pure water could be obtained for diameter, and having each 23 square feet of grate-surface. The chimney was 22 feet high. The great beam, or "lever," of this engine was built up of 20 beams of fir in two sets, placed side by side, and ten deep, strongly bolted together. It was over 6 feet deep at the middle and 5 feet at the ends, and was 2 feet thick. The "main centres," or journals, on which it vibrated were 8½ inches in diameter and 8½ inches long. The cylinder weighed 6½ tons, and was paid for at the rate of 28 shillings per hundredweight.

By the end of the eighteenth century, therefore, the engine of Newcomen, perfected by the ingenuity of Potter and of Beighton, and by the systematic study and experimental research of Smeaton, had become a well-established form of steam-engine, and its application to raising water had become general. The coal-mines of Coventry and of Newcastle had adopted this method of drainage; and the tin and the copper mines of Cornwall had been deepened, using, for drainage, engines of the largest size.

Some engines had been set up in and about London, the scene of Worcester's struggles and disappointments, where they were used to supply water to large houses. Others were in use in other large cities of England, where water-works had been erected.

Some engines had also been erected to drive mills indirectly by raising water to turn water-wheels. This is said by Farey to have been first practised in 1752, at a mill near Bristol, and became common during the next quarter of a century. Many engines had been built in England and sent across the channel, to be applied to the drainage of mines on the Continent. Belidor[1] stated that the manufacture of these "fire-engines" was exclusively confined to England; and this remained true many years after his time. When used for the drainage of mines, the engine usually worked the ordinary lift or bucket pump; when employed

---

[1] "Architecture Hydraulique," 1734.

Smeaton was given the description, in 1773, of a *stone* boiler, which was used with one of these engines at a copper mine at Camborne, in Cornwall. It contained three copper flues 22 inches in diameter. The gases were passed through these flues successively, finally passing off to the chimney. This boiler was cemented with hydraulic mortar. It was 20 feet long, 9 feet wide, and 8½ feet deep. It was heated by the waste heat from the roasting-furnaces. This was one of the earliest flue-boilers ever made.

In 1780, Smeaton had a list of 18 large engines working in Cornwall. The larger number of them were built by Jonathan Hornblower and John Nancarron. At this time, the largest and best-known pumping-engine for waterworks was at York Buildings, in Villiers Street, Strand, London. It had been in operation since 1752, and was erected beside one of Savery's engines, built in 1710. It had a steam-cylinder 45 inches in diameter, and a stroke of piston of 8 feet, making 7½ strokes per minute, and developing 35½ horse-power. Its boiler was dome-shaped, of copper, and contained a large central fire-box and a spiral flue leading outward to the chimney. Another somewhat larger machine was built and placed beside this engine, some time previous to 1775. Its cylinder was 49 inches in diameter, and its stroke 9 feet. It raised water 102 feet. This engine was altered and improved by Smeaton in 1777, and continued in use until 1813.

Smeaton, as early as 1765, designed a *portable* engine,[1] in which he supported the machinery on a wooden frame mounted on short legs and strongly put together, so that the whole machine could be transported and set at work wherever convenient.

In place of the beam, a large pulley was used, over which a chain was carried, connecting the piston with the pump-rod, and the motion was similar to that given by the

---

[1] Smeaton's "Reports," vol. i., p. 228.

machinery of a blast-furnace was erected at the Carron Iron-Works, in Scotland, near Falkirk, in 1765, and proved very unsatisfactory. Smeaton subsequently, in 1769 or 1770, introduced better machinery into these works and improved the old engine, and this use of the steam-engine soon became usual. This engine did its work indirectly, furnishing water, by pumping, to drive the water-wheels which worked the blowing-cylinders. Its steam-cylinder was 6 feet in diameter, and the pump-cylinder 52 inches. The stroke was 9 feet.

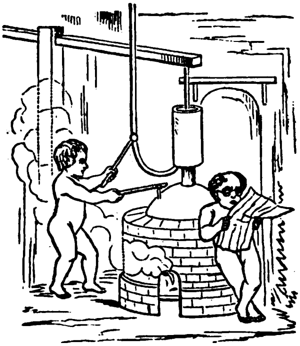
A direct-acting engine, used as a blowing-engine, was not constructed until about 1784, at which time a single-acting blowing-cylinder, or air-pump, was placed at the "outboard" end of the beam, where the pump-rod had been attached. The piston of the air-cylinder was loaded with the weights needed to force it down, expelling the air, and the engine did its work in raising the loaded piston, the air-cylinder filling as the piston rose. A large "accumulator" was used to equalize the pressure of the expelled air. This consisted of another air-cylinder, having a loaded piston which was left free to rise and fall. At each expulsion of air by the blowing-engine this cylinder was filled, the loaded piston rising to the top. While the piston of the former was returning, and the air-cylinder was taking in its charge of air, the accumulator would gradually discharge the stored air, the piston slowly falling under its load. This piston was called the "floating piston," or "fly-piston," and its action was, in effect, precisely that of the upper portion of the common blacksmith's bellows.

Dr. Robison, the author of "Mechanical Philosophy," one of the very few works even now existing deserving such a title, describes one of these engines[1] as working in Scotland in 1790. It had a steam-cylinder 40 or 44 inches in diameter, a blowing-cylinder 60 inches in diameter, and the

---

[1] "Encyclopædia Britannica," 1st edition.

century, the steam-engine had become generally introduced, and had been applied to nearly all of the purposes for which a single-acting engine could be used. The path which had been opened by Worcester had been fairly laid out by Savery and his contemporaries, and the builders of the Newcomen engine, with such improvements as they had been able to effect, had followed it as far as they were able. The real and practical introduction of the steam-engine is as fairly attributable to Smeaton as to any one of the inventors whose names are more generally known in connection with it. As a mechanic, he was unrivaled; as an engineer, he was head and shoulders above any constructor of his time engaged in general practice. There were very few important public works built in Great Britain at that time in relation to which he was not consulted; and he was often visited by foreign engineers, who desired his advice with regard to works in progress on the Continent.



James Watt was of an humble lineage, and was born at Greenock, then a little Scotch fishing village, but now a considerable and a busy town, which annually launches upon the waters of the Clyde a fleet of steamships whose engines are probably, in the aggregate, far more powerful than were all the engines in the world at the date of Watt's birth, January 19, 1736. His grandfather, Thomas Watt, of Crawfordsdyke, near Greenock, was a well-known mathematician about the year 1700, and was for many years a schoolmaster at that place. His father was a prominent citizen of Greenock, and was at various times chief magistrate and treasurer of the town. James Watt was a bright boy, but exceedingly delicate in health, and quite unable to attend school regularly, or to apply himself closely to either study or play. His early education was given by his parents, who were respectable and intelligent people, and the tools borrowed from his father's carpenter-bench served at

James Watt.

engine, and thus independently proved the existence of that "latent heat," the discovery of which constitutes, also, one of the greatest of Dr. Black's claims to distinction. Watt at once went to Dr. Black and related the remarkable fact which he had thus detected, and was, in turn, taught by Black the character of the phenomenon as it had been explained to his classes by the latter some little time previously. Watt found that, at the boiling-point, his steam, condensing, was capable of heating six times its weight of water such as was used for producing condensation.

Perceiving that steam, weight for weight even, was a vastly greater absorbent and reservoir of heat than water, Watt saw plainly the importance of taking greater care to economize it than had previously been customary. He first attempted to economize in the boiler, and made boilers with wooden "shells," in order to prevent losses by conduction and radiation, and used a larger number of flues to secure more complete absorption of the heat from the furnace-gases. He also covered his steam-pipes with non-conducting materials, and took every precaution that his ingenuity could devise to secure complete utilization of the heat of combustion. He soon found, however, that he was not working at the most important point, and that the great source of loss was to be found in defects which he noted in the action of the steam in the cylinder. He soon concluded that the sources of loss of heat in the Newcomen engine—which would be greatly exaggerated in a small model—were:

First, the dissipation of heat by the cylinder itself, which was of brass, and was both a good conductor and a good radiator.

Secondly, the loss of heat consequent upon the necessity of cooling down the cylinder at every stroke, in producing the vacuum.

Thirdly, the loss of power due to the pressure of vapour beneath the piston, which was a consequence of the imperfect method of condensation.

by a master-workman, you must give up a great share of the profit. 3dly. The success of the engine is far from being verified. If Mr. Boulton takes his chance of success from the account I shall write Dr. Small, and pays you any adequate share of the money laid out, it lessens your risk, and in a greater proportion than I think it will lessen your profits. 4thly. The assistance of Mr. Boulton's and Dr. Small's ingenuity (if the latter engage in it) in improving and perfecting the machine may be very considerable, and may enable us to get the better of the difficulties that might otherwise damn it. Lastly, consider my uncertain health, my irresolute and inactive disposition, my inability to bargain and struggle for my own with mankind: all which disqualify me for any great undertaking. On our side, consider the first outlay and interest, the patent, the present engine, about £200 (though there would not be much loss

Matthew Boulton.

that its goods were known to every civilized nation, and its growth, under the management of the enterprising, conscientious, and ingenious Boulton, more than kept pace with the accumulation of capital; and the proprietor found himself, by his very prosperity, often driven to the most careful manipulation of his assets, and to making free use of his credit.

Boulton had a remarkable talent for making valuable acquaintances, and for making the most of advantages accruing thereby. In 1758 he made the acquaintance of Benjamin Franklin, who then visited Soho; and in 1766 these distinguished men, who were then unaware of the existence of James Watt, were corresponding, and, in their letters, discussing the applicability of steam-power to various useful purposes. Between the two a new steam-engine was designed, and a model was constructed by Boulton, which was sent to Franklin and exhibited by him in London.

Dr. Darwin seems to have had something to do with this scheme, and the enthusiasm awakened by the promise of success given by this model may have been the origin of the now celebrated prophetic rhymes so often quoted from the works of that eccentric physician and poet. Franklin contributed, as his share in the plan, an idea of so arranging the grate as to prevent the production of smoke. He says: "All that is necessary is to make the smoke of fresh coals pass descending through those that are already ignited." His idea has been, by more recent schemers, repeatedly brought forward as new. Nothing resulted from these experiments of Boulton, Franklin, and Darwin, and the plan of Watt soon superseded all less well-developed plans.

In 1767, Watt visited Soho and carefully inspected Boulton's establishment. He was very favourably impressed by the admirable arrangement of the workshops and the completeness of their outfit, as well as by the perfection of the organization and administration of the business. In the following year he again visited Soho, and this time met

Boulton, who had been absent at the previous visit. The two great mechanics were mutually gratified by the meeting, and each at once acquired for the other the greatest respect and esteem. They discussed Watt's plans, and Boulton then definitely decided not to continue his own experiments, although he had actually commenced the construction of a pumping-engine. With Dr. Small, who was also at Soho, Watt discussed the possibility of applying his engine to the propulsion of carriages, and to other purposes. On his return home, Watt continued his desultory labours on his engines, as already described; and the final completion of the arrangement with Boulton, which immediately followed the failure of Dr. Roebuck, took place some time later.

Before Watt could leave Scotland to join his partner at Soho, it was necessary that he should finish the work which he had in hand, including the surveys of the Caledonian canal, and other smaller works, which he had had in progress some months. He reached Birmingham in the spring of 1774, and was at once domiciled at Soho, where he set at work upon the partly-made engines which had been sent from Scotland some time previously. They had laid, unused and exposed to the weather, at Kinneil three years, and were not in as good order as might have been desired. The *block-tin* steam-cylinder was probably in good condition, but the iron parts were, as Watt said, "perishing," while he had been engaged in his civil engineering work. At leisure moments, during this period, Watt had not entirely neglected his plans for the utilization of steam. He had given much thought, and had expended some time, in experiments upon the plan of using it in a rotary or "wheel" engine. He did not succeed in contriving any plan which seemed to promise success.

It was in November, 1774, that Watt finally announced to his old partner, Dr. Roebuck, the successful trial of the Kinneil engine. He did not write with the usual enthusiequally on both, so as to raise the weight on one side of the wheel, and, by the reaction of the valves successively, to give a circular motion to the wheel, the valves opening in the direction in which the weights are pressed, but not in the contrary. As the vessel moves round, it is supplied with steam from the boiler, and that which has performed its office may either be discharged by means of condensers, or into the open air.

"6thly. I intend in some cases to apply a degree of cold not capable of reducing the steam to water, but of contracting it considerably, so that the engines shall be worked by the alternate expansion and contraction of the steam.

"Lastly, instead of using water to render the piston or other parts of the engine air or steam-tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state."

In the construction and erection of his engines, Watt still had great difficulty in finding skillful workmen to make the parts with accuracy, to fit them with care, and to erect them properly when once finished. And the fact that both Newcomen and Watt met with such serious trouble, indicates that, even had the engine been designed earlier, it is quite unlikely that the world would have seen the steam-engine a success until this time, when mechanics were just acquiring the skill requisite for its construction. But, on the other hand, it is not at all improbable that, had the mechanics of an earlier period been as skillful and as well-educated in the manual niceties of their business, the steam-engine might have been much earlier brought into use.

In the time of the Marquis of Worcester it would have probably been found impossible to obtain workmen to construct the steam-engine of Watt, had it been then invented. Indeed, Watt, upon one occasion, congratulated himself that one of his steam-cylinders only lacked *three-eighths* of an inch of being truly cylindrical.

The history of the steam-engine is from this time a history of the work of the firm of Boulton & Watt. Newcomen engines continued to be built for years after Watt went to Soho, and by many builders. A host of inventors still worked on the most attractive of all mechanical combinations, seeking to effect further improvements. Some inventions were made by contemporaries of Watt, as will be seen hereafter, which were important as being the germs of later growths ; but these were nearly all too far in advance of the time, and nearly every successful and important invention which marked the history of steam-power for many years originated in the fertile brain of James Watt.

The defects of the Newcomen engine were so serious, that it was no sooner known that Boulton of Soho had become interested in a new machine for raising water by steam-power, than inquiries came to him from all sides, from mine-owners who were on the point of being drowned out, and from proprietors whose profits were absorbed by the expense of pumping, and who were glad to pay the £5 per horse-power per year finally settled upon as royalty. The London municipal water-works authorities were also ready to negotiate for pumping-engines for raising water to supply the metropolis. The firm was therefore at once driven to make preparations for a large business.

The first and most important matter, however, was to secure an extension of the patent, which was soon to expire. If not renewed, the 15 years of study and toil, of poverty and anxiety, through which Watt had toiled, would prove profitless to the inventor, and the fruits of his genius would have become the unearned property of others. Watt saw, at one time, little hope of securing the necessary act of Parliament, and was greatly tempted to accept a position tendered him by the Russian Government, upon the solicitation of his old friend, Dr. Robison, then a Professor of Mathematics at the Naval School at Cronstadt. The salary was £1,000—a princely income for a man in Watt's circumstances, and a peculiar temptation to the needy mechanic.

Watt, however, went to London, and, with the help of his own and of Boulton's influential friends, succeeded in getting his bill through. His patent was extended 24 years, and Boulton & Watt set about the work of introducing their engines with the industry and enterprise which characterized their every act.

In the new firm, Boulton took charge of the general business, and Watt superintended the design, construction, and erection of their engines. Boulton's business capacity, with Watt's wonderful mechanical ability—Boulton's physical health, and his vigour and courage, offsetting Watt's feeble health and depression of spirits—and, more than all, Boulton's pecuniary resources, both in his own purse and in those of his friends, enabled the firm to conquer all difficulties, whether in finance, in litigation, or in engineering.

It was only after the successful erection and operation of several engines that Boulton and Watt became legally partners. The understood terms were explicitly stated by Watt to include an assignment to Boulton of two-thirds the patent-right; Boulton paying all expenses, advancing stock in trade at an appraised valuation, on which it was to draw interest; Watt making all drawings and designs, and drawing one-third net profits.

As soon as Watt was relieved of the uncertainties regarding his business connections, he married a second wife, who, as Arago says, by "her various talent, soundness of judgment, and strength of character," made a worthy companion to the large-hearted and large-brained engineer. Thenceforward his cares were only such as every business-man expects to be compelled to sustain, and the next ten years were the most prolific in inventions of any period in Watt's life.

From 1775 to 1785 the partners acquired five patents, covering a large number of valuable improvements upon the steam-engine, and several independent inventions. The first of these patents covered the now familiar and universally-used copying-press for letters, and a machine for drying cloth by passing it between copper rollers filled with steam of sufficiently high temperature to rapidly evaporate the moisture. This patent was issued February 14, 1780.

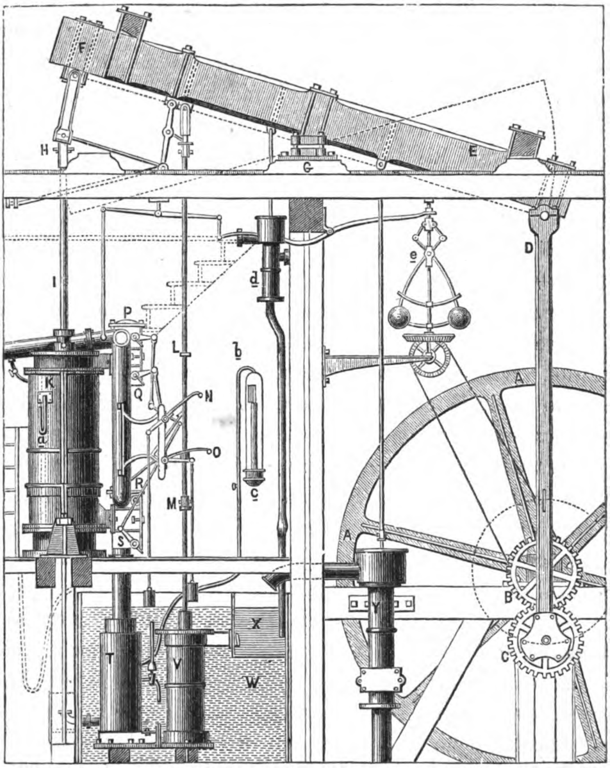


Fig. 27.—Watt's Engine, 1781.

In the following year, October 25, 1781, Watt patented five devices by which he obtained the rotary motion of the engine-shaft without the use of a crank. One of these was the arrangement shown in Fig. 27, and known as the "sun-and from the metal of the cylinder, tends to compensate the first variation by a reverse change of pressure with change of volume.

The sketch shows this progressive variation of pressure as expansion proceeds. It is seen that the work done per unit of volume of steam as taken from the boiler is much greater than when working without expansion. The product of the mean pressure by the volume of the cylinder is less, but the quotient obtained by dividing this quantity by the volume or weight of steam taken from the boiler, is much greater with than without expansion. For the case assumed and illustrated, the work done during expansion is one and two-fifths times that done previous to cutting off the steam, and the work done per pound of steam is 2.4 times that done without expansion.

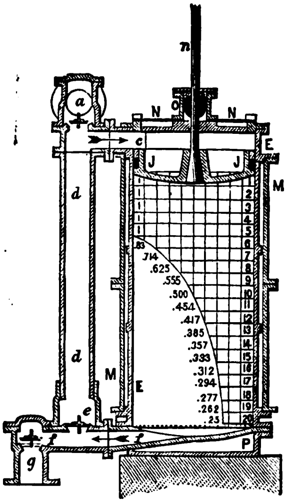


FIG. 28.—Expansion of Steam.

Were there no losses to be met with and to be exaggerated by the use of steam expansively, the gain would become very great with moderate expansion, amounting to twice the work done when "following" full stroke, when the steam is cut off at one-seventh. The estimated gain is, however, never realized. Losses by friction, by conduction and radiation of heat, and by condensation and reëvaporation in the cylinder—of which losses the latter are most serious—after passing a point which is variable, and which is determined by the special conditions in each case, augment with greater rapidity than the gain by expansion.

In actual practice, it is rarely found, except where special precautions are taken to reduce these losses, that economy follows expansion to a greater number of volumes than about one-half the square root of the steam-pressure; i. e., about twice for 15 or 20 pounds pressure, three times for about 30 pounds, and four and five times for 60 or 65 and for 100 to 125 pounds respectively. Watt very soon learned this general principle; but neither he, nor even many modern engineers, seem to have learned that too great expansion often gives greatly-reduced economy.

The inequality of pressure due to expansion, to which he refers, was a source of much perplexity to Watt, as he was for a long time convinced that he must find some method of "equalizing" the consequent irregular effort of the steam upon the piston. The several methods of "equalizing the expansive power" which are referred to in the patent were attempts to secure this result. By one method, he shifted the centre as the beam vibrated, thus changing the lengths of the arms of that great lever, to compensate the change of moment consequent upon the change of pressure. He finally concluded that a fly-wheel, as first proposed by Fitzgerald, who advised its use on Papin's engine, would be the best device on engines driving a crank, and trusted to the inertia of a balance-weight in his pumping-engines, or to the weight of the pump-rods, and permitted the piston to take its own speed so far as it was not thus controlled.

The double-acting engine was a modification of the sinhead of the piston-rod, *g*, was guided by rods connecting it with the frame at *c*, and forming a "parallelogram," *g d e b*, with the beam. Many varieties of "parallel-motion" have been devised since Watt's invention was attached to his engines at Soho. They usually are more or less imperfect, guiding the piston-rod in a line only approximately straight.

The cross-head and guides are now generally used, very much as described by Watt in this patent as his "second principle." This device will be seen in the engravings given hereafter of more modern engines. The head of the piston-rod is fitted into a transverse bar, or cross-head, which carries properly-shaped pieces at its extremities, to which are bolted "gibs," so made as to fit upon guides secured to the engine-frame. These guides are adjusted to precise parallelism with the centre line of the cylinder. The cross-head, sliding in or on these guides, moves in a perfectly straight line, and, compelling the piston-rod to move with it, the latter is even more perfectly guided than by a parallel-motion. This arrangement, where properly proportioned, is not necessarily subject to great friction, and is much more easily adjusted and kept in line than the parallel-motion when wear occurs or maladjustment takes place.

By the same patent, Watt secured the now common "puppet-valve," with beveled seat, and the application of the steam-engine to driving rolling-mills and hammers for forges, and to "wheel-carriages for removing persons or goods, or other matters, from place to place." For the latter purpose he proposes to use boilers "of wood, or of thin metal, strongly secured by hoops or otherwise," and containing "internal fire-boxes." He proposed to use a condenser cooled by currents of air.

It would require too much space to follow Watt in all his schemes for the improvement and for the application of the steam-engine. A few of the more important and more ingenious only can be described. Many of the contracts of

Boulton & Watt gave them, as compensation for their engines, a fraction—usually one-third—of the value of the fuel saved by the use of the Watt engine in place of the engine of Newcomen, the amount due being paid annually or semiannually, with an option of redemption on the part of the purchaser at ten years' purchase. This form of agreement compelled a careful determination, often, of the work done and fuel consumed by both the engine taken out and that put in its place. It was impossible to rely upon any determination by personal observation of the number of strokes made by the engine. Watt therefore made a "counter," like that now familiar to every one as used on gas-meters. It consists of a train of wheels moving pointers on several dials, the first dial showing tens, the second hundreds, the third thousands, etc., strokes or revolutions. Motion was communicated to the train by means of a pendulum, the whole being mounted on the beam of the engine, where every vibration produced a swing of the pendulum. Eight dials were sometimes used, the counter being set and locked, and only opened once a year, when the time arrived for determining the work done during the preceding twelvemonth.

The application of his engine to purposes for which careful adjustment of speed was requisite, or where the load was subject to considerable variation, led to the use of a controlling-valve in the steam-pipe, called the "throttle-valve," which was adjustable by hand, and permitted the supply of steam to the engine to be adjusted at any instant and altered to any desired extent. It is now given many forms, but it still is most usually made just as originally designed by Watt. It consists of a circular disk, which just closes up the steam-pipe when set directly across it, or of an elliptical disk, which closes the pipe when standing at an angle of somewhat less than 90° with the line of the pipe. This disk is carried on a spindle extending through the pipe at one side, and carrying on its outer end an arm by means of which it may be turned into any position. When placed with its face in line with the pipe, it offers very little resistance to the flow of steam to the engine. When set in the other position, it shuts off steam entirely and stops the engine. It is placed in such position at any time, that the speed of the engine is just that required at the time. In the engraving of the double-acting engine with fly-wheel (Fig. 31), it is shown at *T*, as controlled by the governor.

The governor, or "fly-ball governor," as it is often distinctively called, was another of Watt's minor but very essential inventions. Two heavy iron or brass balls, *B B′*, were suspended from pins, *C C′*, in a little cross-piece carried on the head of a vertical spindle, *A A′*, driven by the engine. The speed of the engine varying, that of the spindle changed correspondingly, and the faster the balls were swung the farther they separated. When the engine's speed decreased, the period of revolution of the balls was increased, and they fell back toward the spindle. Whenever the velocity of the engine was uniform, the balls preserved their distance from the spindle and remained at the same height, their

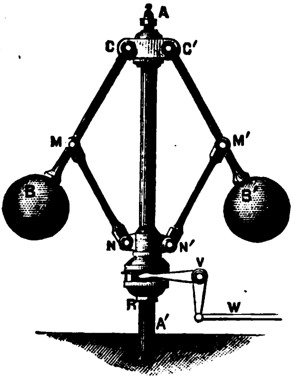


FIG. 29.—The Governor.

altitude being determined by the relation existing between the force of gravity and centrifugal force in the temporary position of equilibrium. The distance from the point of suspension down to the level of the balls is always equal to 9.78 inches divided by the square of the number of revolutions per second—i. e., $h = 9.78\frac{1}{N^2}$.

The arms carrying the balls, or the balls themselves, are pinned to rods, MM', which are connected to a piece, NN', sliding loosely on the spindle. A score, T, cut in this piece engages a lever, V, and, as the balls rise and fall, a rod, W, is moved, closing and opening the throttle-valve, and thus adjusting the supply of steam in such a way as to preserve a nearly fixed speed of engine. The connection with the throttle-valve and with the cut-off valve-gear is seen not only in the engraving of the double-acting Watt engine, but also in those of the Greene and the Corliss engines. This contrivance had previously been used in regulating water-wheels and windmills. Watt's invention consisted in its application to the regulation of the steam-engine.

Still another useful invention of Watt's was his "mercury steam-gauge"—a barometer in which the height of the mercury was determined by the pressure of the steam instead of that of the atmosphere. This simple instrument consisted merely of a bent tube containing a portion of mercury. One leg, BD, of this U-tube was connected with the steam-pipe, or with the boiler by a small steam-pipe; the other end, C, was open to the atmosphere. The pressure of the steam on the mercury in BD caused it to rise in the other "leg" to a height exactly proportioned to the pressure, and causing very nearly two inches difference of level to the pound, or one inch to the pound actual rise in the outer leg. The rude sketch from Farey, here given (Fig. 30), indicates sufficiently well the form of this gauge. It is still considered by engineers the most reliable of all forms of steam-gauge. Unfortunately, it is not conveniently apranged boiler. This was a glass tube, *a a′* (Fig. 30), mounted on a standard attached to the front of the boiler, and at such a height that its middle point was very little below the proposed water-level. It was connected by a small pipe, *r*, at the top to the steam-space, and another little pipe, *r′*, led into the boiler from its lower end below the water-line. As the water rose and fell within the boiler, its level changed correspondingly in the glass. This little instrument is especially liked, because the position of the water is at all times shown to the eye of the attendant. If carefully protected against sudden changes of temperature, it answers perfectly well with even very high pressures.

The engines built by Boulton & Watt were finally fitted with the crank and fly-wheel for application to the driving of mills and machinery. The accompanying engraving (Fig. 31) shows the engine as thus made, combining all of the essential improvements designed by its inventor.

In the engraving, *C* is the steam-cylinder, *P* the piston, connected to the beam by the link, *g*, and guided by the parallel-motion, *g d c*. At the opposite end of the beam a connecting-rod, *O*, connects with the crank and fly-wheel shaft. *R* is the rod of the air-pump, by means of which the condenser is kept from being flooded by the water used for condensation, which water-supply is regulated by an "injection-handle," *E*. A pump-rod, *N*, leads down from the beam to the cold-water pump, by which water is raised from the well or other source to supply the needed injection-water. The air-pump rod also serves as a "plug-rod," to work the valves, the pins at *m* and *R* striking the lever, *m*, at either end of the stroke. When the piston reaches the top of the cylinder, the lever, *m*, is raised, opening the steam-valve, *B*, at the top, and the exhaust-valve, *E*, at the bottom, and at the same time closing the exhaust at the top and the steam at the bottom. When the entrance of steam at the top and the removal of steam-pressure below the piston has driven the piston to the bottom, the pin, *R*, strikes the lever, *m*, opening the steam and closing the exhaust valve at the bottom, and similarly reversing the position of the valves at the top. The position of the valves is changed in this manner with every reversal of the motion of the piston as the crank "turns over the centre."

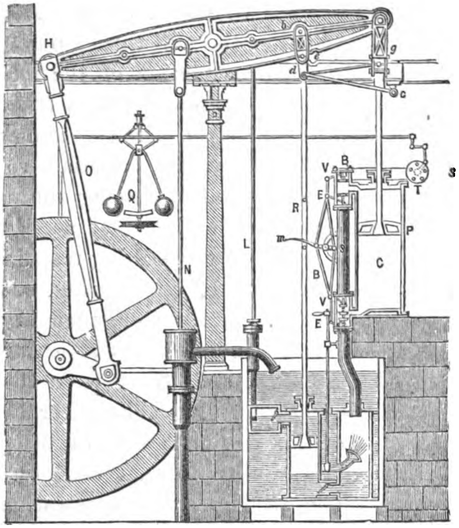


Fig. 81.—Boulton & Watt's Double-Acting Engine, 1784.

The earliest engines of the double-acting kind, and of any considerable size, which were built to turn a shaft, were those which were set up in the Albion Mills, near Blackfriars Bridge, London, in 1786, and destroyed when the mills burned down in 1791. There were a pair of these engines (shown in Fig. 27), of 50 horse-power each, and geared to drive 20 pairs of stones, making fine flour and meal. Previous to the erection of this mill the power in all such establishments had been derived from windmills and water-wheels. This mill was erected by Boulton & Watt, and capitalists working with them, not only to secure the profit anticipated from locating a flour-mill in the city of London, but also with a view to exhibiting the capacity of the new double-acting " rotating " engine. The plan was proposed in 1783, and work was commenced in 1784; but the mill was not set in operation until the spring of 1786. The capacity of the mill was, in ordinary work, 16,000 bushels of wheat ground into fine flour per week. On one occasion, the mill turned out 3,000 bushels in 24 hours. In the construction of the machinery of the mill, many improvements upon the then standard practice were introduced, including cast-iron gearing with carefully-formed teeth and iron framing. It was here that John Rennie commenced his work, after passing through his apprenticeship in Scotland, sending his chief assistant, Ewart, to superintend the erection of the milling machinery. The mill was a success as a piece of engineering, but a serious loss was incurred by the capitalists engaged in the enterprise, as it was set on fire a few years afterward and entirely destroyed. Boulton and Watt were the principal losers, the former losing £6,000, and the latter £3,000.

The valve-gear of this engine, a view of which is given in Fig. 27, was quite similar to that used on the Watt pumping-engine. The accompanying illustration (Fig. 32) represents this valve-motion as attached to the Albion Mills engine.

The steam-pipe, *a b d d e*, leads the steam from the boiler to the chambers, *b* and *e*. The exhaust-pipe, *g g*, leads from *h* and *i* to the condenser. In the sketch, the upper steam and the lower exhaust valves, *b* and *f*, are opened, and the steam-valve, *e*, and exhaust-valve, *c*, are closed, the piston being near the upper end of the cylinder and descending. *L* represents the plug-frame, which carries tappets, 2 and 3, which engage the lever, *s*, at either end of its throw, and turn the shaft, *u*, thus opening and closing *c* and *e* simultaneously by means of the connecting-links, 13 and

14. A similar pair of tappets on the opposite side of the plug-rod move the valves, *b* and *f*, by means of the rods, 10 and 11, the arm, *r*, when struck by those tappets, turning the shaft, *t*, and thus moving the arms to which those rods are attached. Counterbalance-weights, carried on the ends of the arms, 4 and 15, retain the valves on their seats when closed by the action of the tappets. When the piston nearly reaches the lower end of the cylinder, the tappet, 1, engages the arm, *r*, closing the steam-valve, *b*, and the next instant shutting the exhaust-valve, *f*. At the same time, the tappet, 3, by moving the arm, *s*, downward, opens the steam-valve, *e*, and the exhaust-valve, *c*. Steam now no longer issues from the steam-pipe into the space, *c*, and thence into the engine-cylinder (not shown in the sketch); but it now enters the engine through the valve, *e*, forcing the piston

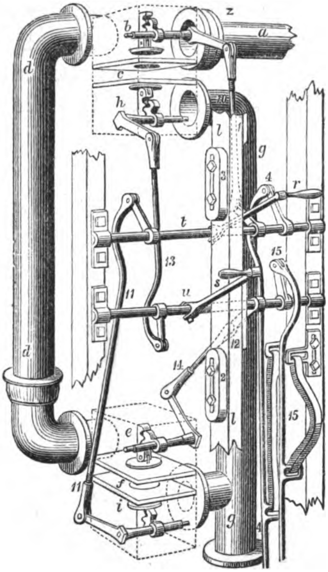


FIG. 32.—Valve-Gear of the Albion Mills Engine.

upwards. The exhaust is simultaneously made to occur at the upper end, the rejected steam passing from the engine into the space, *c*, and thence through *c* and the pipe, *g*, into the condenser.

This kind of valve-gear was subsequently greatly improved by Murdoch, Watt's ingenious and efficient foreman, but it is now entirely superseded on engines of this class by the eccentric, and the various forms of valve-gear driven by it.

The "trunk-engine" was still another of the almost innumerable inventions of Watt. A half-trunk engine is described in his patent of 1784, as shown in the accompanying sketch (Fig. 33), in which *A* is the cylinder, *B* the piston, and *C* its rod, encased in the half-trunk, *D*. The plug-rod, *G*, moves the single pair of valves by striking the catches, *E* and *F*, as was usual with Watt's earlier engines,

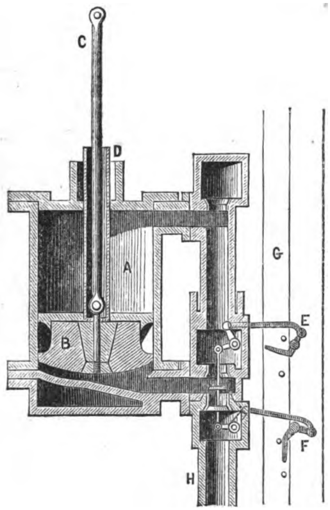


FIG. 33.—Watt's Half-Trunk Engine, 1784.

Watt's steam-hammer was patented at the same time. It is seen in Fig. 34, in which *A* is the steam-cylinder and *B* its rod, the engine being evidently of the form just described. It works a beam, *C C*, which in turn, by the rod, *M*, works the hammer-helve, *L J*, and the hammer, *L*. The beam, *F G*, is a spring, and the block, *N*, the anvil.

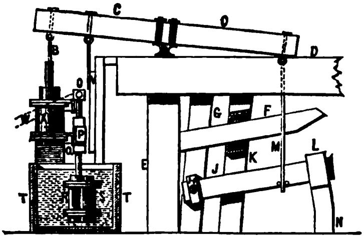


Fig. 84.—The Watt Hammer, 1784.

Watt found it impossible to determine the duty of his engines at all times by measurement of the work itself, and endeavoured to find a way of ascertaining the power produced, by ascertaining the pressure of steam within the cylinder. This pressure was so variable, and subject to such rapid as well as extreme fluctuations, that he found it impossible to make use of the steam-gauge constructed for use on the boiler. He was thus driven to invent a special instrument for this work, which he called the "steam-engine indicator." This consisted of a little steam-cylinder containing a nicely-fitting piston, which moved without noticeable friction through a range which was limited by the compression of a helical spring, by means of which the piston was secured to the top of its cylinder. The distance through which the piston rose was proportional to the pressure exerted upon it, and a pointer attached to its rod traversed a scale upon which the pressure per square inch could be read. The lower end of the instrument being connected with the steam-cylinder of the than the stethoscope of the physician gives him a knowledge of the condition and working of organs contained within the human body. This indispensable and now familiar engineers' instrument has since been modified and greatly improved in detail.

The Watt engine had, by the construction of the improvements described in the patents of 1782–'85, been given its distinctive form, and the great inventor subsequently did little more than improve it by altering the forms and proportions of its details. As thus practically completed, it embodied nearly all the essential features of the modern engine; and, as we have seen, the marked features of our latest practice—the use of the double cylinder for expansion, the cut-off valve-gear, and surface-condensation—had all been proposed, and to a limited extent introduced. The growth of the steam-engine has here ceased to be rapid, and the changes which followed the completion of the work of James Watt have been minor improvements, and rarely, if ever, real developments.

Watt's mind lost none of its activity, however, for many years. He devised and patented a "smoke-consuming furnace," in which he led the gases produced on the introduction of fresh fuel over the already incandescent coal, and thus burned them completely. He used two fires, which were coaled alternately. Even when busiest, also, he found time to pursue more purely scientific studies. With Boulton, he induced a number of well-known scientific men living near Birmingham to join in the formation of a "Lunar Society," to meet monthly at the houses of its members, "at the full of the moon." The time was thus fixed in order that those members who came from a distance should be able to drive home, after the meetings, by moonlight. Many such societies were then in existence in England; but that at Birmingham was one of the largest and most distinguished of them all. Boulton, Watt, Drs. Small, Darwin, and Priestley, were the leaders, and among their occasional visitors were Herschel, Smeaton, and Banks. Watt called these meetings "Philosophers' meetings." It was during the period of most active discussion at the "philosophers' meetings" that Cavendish and Priestley were experimenting with mixtures of oxygen and hydrogen, to determine the nature of their combustion. Watt took much interest in the subject, and, when informed by Priestley that he and Cavendish had both noticed a deposit of moisture invariably succeeding the explosion of the mixed gases, when contained in a cold vessel, and that the weight of this water was approximately equal to the weight of the mixed gases, he at once came to the conclusion that the union of hydrogen with oxygen produced water, the latter being a chemical compound, of which the former were constituents. He communicated this reasoning, and the conclusions to which it had led him, to Boulton, in a letter written in December, 1782, and addressed a letter some time afterward to Priestley, which was to have been read before the Royal Society in April, 1783. The letter was not read, however, until a year later, and, three months after, a paper by Cavendish, making the same announcement, had been laid before the Society. Watt stated that both Cavendish and Lavoisier, to whom also the discovery is ascribed, received the idea from him.

The action of chlorine in bleaching organic colouring matters, by (as since shown) decomposing them and combining with their hydrogen, was made known to Watt by M. Berthollet, the distinguished French chemist, and the former immediately introduced its use into Great Britain, by inducing his father-in-law, Mr. Macgregor, to make a trial of it.

The copartnership of Boulton & Watt terminated by limitation, and with the expiration of the patents under which they had been working, in the first year of the present century; and both partners, now old and feeble, withdrew from active business, leaving their sons to renew the agree-iron which he was last employed in turning, lay on the lathe. The ashes of the last fire were in the grate; the last bit of coal was in the scuttle. The Dutch oven was in its place over the stove, and the frying-pan in which he cooked his meals was hanging on its accustomed nail. Many objects lay about or in the drawers, indicating the pursuits which had been interrupted by death—busts, medallions, and figures, waiting to be copied by the copying-machine—many medallion-moulds, a store of plaster-of-Paris, and a box of plaster casts from London, the contents of which do not seem to have been disturbed. Here are Watt's ladles for melting lead, his foot-rule, his glue-pot, his hammer. Reflecting mirrors, an extemporized camera with the lenses mounted on pasteboard, and many camera-glasses laid about, indicate interrupted experiments in optics. There are quadrant-glasses, compasses, scales, weights, and sundry boxes of mathematical instruments, once doubtless highly prized. In one place a model of the governor, in another of the parallel-motion, and in a little box, fitted with wooden cylinders mounted with paper and covered with figures, is what we suppose to be a model of his calculating-machine. On the shelves are minerals and chemicals in pots and jars, on which the dust of nearly half a century has settled. The moist substances have long since dried up; the putty has been turned to stone, and the paste to dust. On one shelf we come upon a dish in which lies a withered bunch of grapes. On the floor, in a corner, near to where Watt sat and worked, is a hair-trunk—a touching memorial of a long-past love and a long-dead sorrow. It contains all poor Gregory's school-books, his first attempts at writing, his boy's drawings of battles, his first school-exercises down to his college-themes, his delectuses, his grammars, his dictionaries, and his class-books—brought into this retired room, where the father's eye could rest upon them. Near at hand is the sculpture-machine, on which he continued working to the last. Its wooden frame is worm-eaten, and dropping into dust, like the hands that made it. But though the great workman is gone to rest, with all his griefs and cares, and his handiwork is fast crumbling to decay, the spirit of his work, the thought which he put into his inventions, still survives, and will probably continue to influence the destinies of his race for all time to come."

The visitor to Westminster Abbey will find neither monarch, nor warrior, nor statesman, nor poet, honoured with a nobler epitaph than that which is inscribed on the pedestal of Chantrey's monument to Watt:

Not to perpetuate a Name,
which must endure while the peaceful arts flourish,
but to show
that mankind have learnt to honour those who best deserve their gratitude,
THE KING,
his ministers, and many of the nobles and commoners of the realm,
raised this monument to
JAMES WATT,
who, directing the force of an original genius,
early exercised in philosophic research,
to the improvement of
THE STEAM-ENGINE,
enlarged the resources of his country, increased the power of man,
and rose to an eminent place
among the most illustrious followers of science and the real benefactors of the world.

Born at Greenock, MDCCXXXVI.
Died at Heathfield, in Staffordshire, MDCCCXIX.

many independent inventions, but also for the suggestions and improvements which were often indispensable to the formation and perfection of some of Watt's own inventions.

Murdoch was employed by Boulton & Watt in 1776, and was made superintendent of construction in the engine department, and given general charge of the erection of engines. He was sent into Cornwall, and spent in that district much of the time during which he served the firm, erecting pumping-engines, the construction of which for so many years constituted a large part of the business of the Soho establishment. He was looked upon by both Boulton and Watt as a sincere friend, as well as a loyal adherent, and from 1810 to 1830 was given a partner's share of the income of the firm, and a salary of £1,000. He retired from business at the last of the two dates named, and, dying in 1839, was buried near the two partners in Handsworth Church.

Murdoch made a model, in 1784, of the locomotive patented by Watt in that year. He devised the arrangement of "sun-and-planet wheels," adopted for a time in all of Watt's "rotative" engines, and invented the oscillating steam-engine (Fig. 36) in 1785, using the "D-slide valves," *G*, moved by the gear, *E*, which was driven by an eccentric on the shaft, without regard to the oscillation of the cylinder, *A*. He was the inventor of a rotary engine and of many minor machines for special purposes, and of many machine-tools used at Soho in building engines and machines. He seems, like Watt, to have had special fondness for the worm-gear, and introduced it wherever it could properly take the place of ordinary gearing. Some of the machines designed by Watt and Murdoch, who always worked well together, were found still in use and in good working condition by the author when visiting the works at Soho in 1873. The old mint in which, from 1797 to 1805, Boulton had coined 4,000 tons of copper, had then been pulled down, and a new mint had been erected in 1860.

Many old machines still remained about the establishment as souvenirs of the three great mechanics.

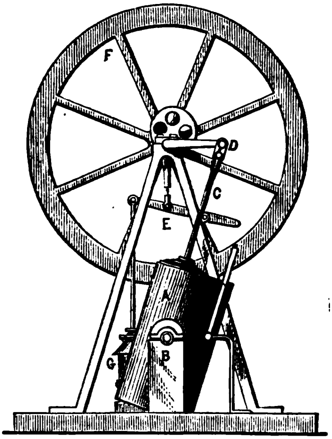


FIG. 36.—Murdoch's Oscillating Engine, 1785.

Outside of Soho, Murdoch also found ample employment for his inventive talent. In 1792, while at Redruth, his residence before finally returning to Soho, he was led to speculate upon the possibility of utilizing the illuminating qualities of coal-gas, and, convinced of its practicability, he laid the subject before the Royal Society in 1808, and was awarded the Rumford gold medal. He had, ten years earlier, lighted a part of the Soho works with coal-gas, and in 1803 Watt authorized him to extend his pipes throughout all the buildings. Several manufacturers promptly introduced the new light, and its use extended very rapidly.

Still another of Murdoch's favourite schemes was the transmission of power by the use of compressed air. He drove the pattern-shop engine at Soho by means of air from the blowing-engine in the foundery, and erected a pneumatic lift to elevate castings from the foundery-floor to the canal-bank. He made a steam-gun, introduced the heating of buildings by the circulation of hot water, and invented the method of transmitting packages through tubes by the impulse of compressed air, as now practised by the "pneumatic dispatch" companies. He died at the age of eighty-five years.

Among the most active and formidable of Watt's business rivals was JONATHAN HORNBLOWER, the patentee of the "compound" or double-cylinder engine. A sketch of this engine, as patented by Hornblower in 1781, is here given (Fig. 37). It was first described by the inventor in the "Encyclopædia Britannica." It consists, as is seen by reference to the engraving, of two steam-cylinders, *A* and *B*—*A* being the low and *B* the high pressure cylinder—the steam leaving the latter being exhausted into the former, and, after doing its work there, passing into the condenser, as already described. The piston-rods, *C* and *D*, are both connected to the same part of the beam by chains, as in the other early engines. These rods pass through stuffing-boxes in the cylinder-heads, which are fitted up like those seen on the Watt engine. Steam is led to the engine through the pipe, *G Y*, and cocks, *a*, *b*, *c*, and *d*, are adjustable, as required, to lead steam into and from the cylinders, and are moved by the plug-rod, *W*, which actuates handles not shown. *K* is the exhaust-pipe leading to the condenser. *V* is the engine feed-pump rod, and *X* the great rod carrying the pump-buckets at the bottom of the shaft.

The cocks *c* and *a* being open and *b* and *d* shut, the steam passes from the boiler into the upper part of the steam-cylinder, *B*; and the communication between the lower part of *B* and the top of *A* is also open. Before starting, steam being shut off from the engine, the great weight of the pump-rod, *X*, causes that end of the beam to preponderate, the pistons standing, as shown, at the top of their respective steam-cylinders.

The engine being freed from all air by opening all the valves and permitting the steam to drive it through the engine and out of the condenser through the "snifting-valve," *O*, the valves *b* and *d* are closed, and the cock in the exhaust-pipe opened.

The steam beneath the piston of the large cylinder is immediately condensed, and the pressure on the upper side of that piston causes it to descend, carrying that end of the beam with it, and raising the opposite end with the pump-rods and their attachments. At the same time, the steam from the lower end of the small high-pressure cylinder being let into the upper end of the larger cylinder, the completion of the stroke finds a cylinder full of steam transferred from the one to the other with corresponding increase of volume and decrease of pressure. While expanding and diminishing in pressure as it passes from the smaller into the larger

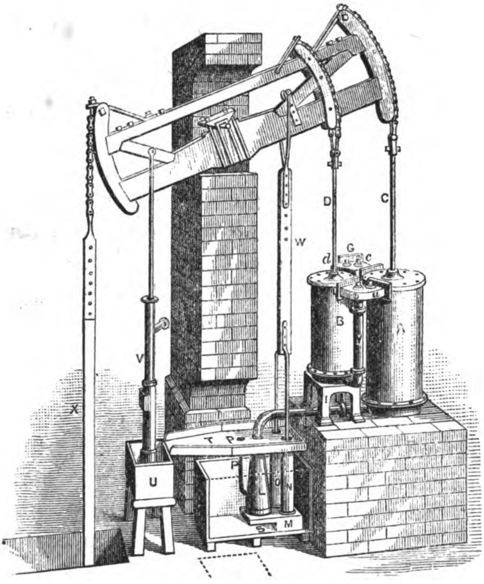


FIG. 87.—Hornblower's Compound Engine, 1781.

gine, and was condensed by contact with the metal surfaces. Cold water within the smaller and surrounding the exterior vessel kept the metal cold, and absorbed the heat discharged by the condensing vapour.

Cartwright's engine is best described in the *Philosophical Magazine* of June, 1798, from which the accompanying sketch is copied.

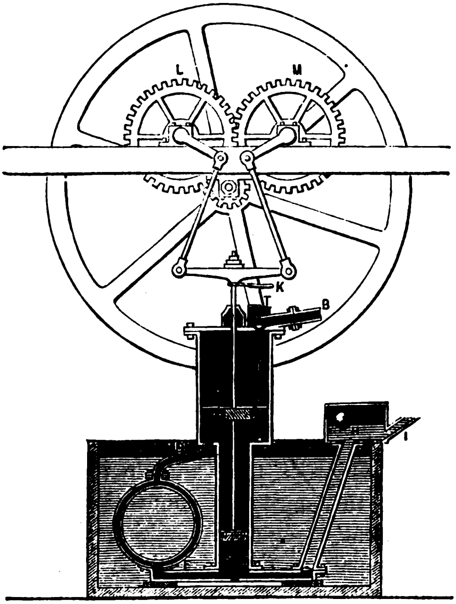


Fig. 39.—Cartwright's Engine, 1798.

The object of the inventor is stated to have been to remedy the defects of the Watt engine—imperfect vacuum, friction, and complication.

In the figure, the steam-cylinder takes steam through the pipe, *B*. The piston, *R*, has a rod extending downward to the smaller pump-piston, *G*, and upward to the cross-head, which, in turn, drives the cranks above, by means of connecting-rods. The shafts thus turned are connected by a pair of gears, *M L*, of which one drives a pinion on the shaft of the fly-wheel. *D* is the exhaust-pipe leading to the condenser, *F*; and the pump, *G*, removes the air and water of condensation, forcing it into the hot-well, *H*, whence it is returned to the boiler through the pipe, *I*. A float in *H* adjusts an air-valve, so as to keep a supply of air in the chamber, to serve as a cushion and to make an air-chamber of the reservoir, and permits the excess to escape. The large tank contains the water supplied for condensing the steam.

The piston, *R*, is made of metal, and is packed with two sets of cut metal rings, forced out against the sides of the cylinder by steel springs, the rings being cut at three points in the circumference, and kept in place by the springs. The arrangement of the two cranks, with their shafts and gears, is intended to supersede Watt's plan for securing a perfectly rectilinear movement of the head of the piston-rod, without friction.

In the accounts given of this engine, great stress is laid upon the supposed important advantage here offered, by the introduction of the surface-condenser, of permitting the employment of a working-fluid other than steam—as, for example, alcohol, which is too valuable to be lost. It was proposed to use the engine in connection with a still, and thus to effect great economy by making the fuel do double duty. The only part of the plan which proved both novel and valuable was the metallic packing and piston, which has not yet been superseded. The engine itself never came into use.

At this point, the history of the steam-engine becomes the story of its applications in several different directions, the most important of which are the raising of water—which had hitherto been its only application—the locomotive-engine, the driving of mill-machinery, and steam-navigation.

Here we take leave of James Watt and of his contemporaries, of the former of whom a French author[1] says: "The part which he played in the mechanical applications of the power of steam can only be compared to that of Newton in astronomy and of Shakespeare in poetry." Since the time of Watt, improvements have been made principally in matters of mere detail, and in the extension of the range of application of the steam-engine.

---

[1] Bataille, "Traité des Machines à Vapeur," Paris, 1847.

CHAPTER IV.

THE MODERN STEAM-ENGINE.

"Those projects which abridge distance have done most for the civilization and happiness of our species."—Macaulay.

The Second Period of Application—1800–'40.
Steam-Locomotion on Railroads.

Introductory.—The commencement of the nineteenth century found the modern steam-engine fully developed in all its principal features, and fairly at work in many departments of industry. The genius of Worcester, and Morland, and Savery, and Desaguliers, had, in the first period of the

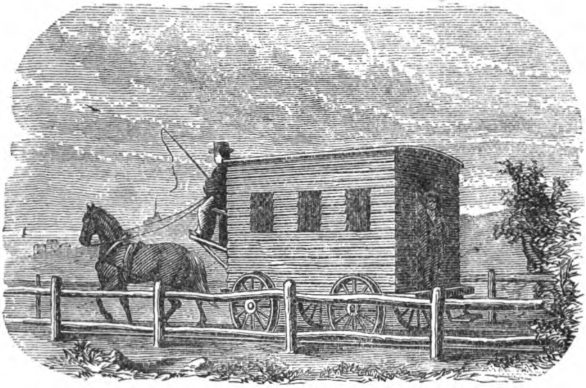


Fig. 40.—The First Railroad-Car, 1825.

application of the power of steam to useful work, effected a beginning which, looked upon from a point of view which exhibits its importance as the first step toward the wonderful results to-day familiar to every one, appears in its true light, and entitles those great men to even greater honour than has been accorded them. The results actually accomplished, however, were absolutely insignificant in comparison with those which marked the period of development just described. Yet even the work of Watt and of his contemporaries was but a mere prelude to the marvellous advances made in the succeeding period, to which we are now come, and, in extent and importance, was insignificant in comparison with that accomplished by their successors in the development of all mechanical industries by the application of the steam-engine to the movement of every kind of machine.

The first of the two periods of application saw the steam-engine adapted simply to the elevation of water and the drainage of mines; during the second period it was adapted to every variety of useful work, and introduced wherever the muscular strength of men and animals, or the power of wind and of falling water, which had previously been the only motors, had found application. A history of the development of industries by the introduction of steam-power during this period, would be no less extended and hardly less interesting than that of the steam-engine itself.

The way had been fairly opened by Boulton and Watt; and the year 1800 saw a crowd of engineers and manufacturers entering upon it, eager to reap the harvest of distinction and of pecuniary returns which seemed so promising to all. The last year of the eighteenth century was also the last of the twenty-five years of partnership of Boulton & Watt, and, with it, the patents under which that firm had held the great monopoly of steam-engine building expired. The right to manufacture the modern steam-engine was common to all. Watt had, at the commencement of the new century, retired from active business-life. Boulton remained in business; but he was not the inventor of the new engine, and could not retain, by the exercise of all his remaining power, the privileges previously held by legal authorization.

The young Boulton and the young Watt were not the Boulton & Watt of earlier years; and, had they possessed all of the business talent and all of the inventive genius of their fathers, they could not have retained control of a business which was now growing far more rapidly than the facilities for manufacturing could be extended in any single establishment. All over the country, and even on the Continent of Europe, and in America, thousands of mechanics, and many men of mechanical tastes in other professions, were familiar with the principles of the new machine, and were speculating upon its value for all the purposes to which it has since been applied; and a multitude of enthusiastic mechanics, and a larger multitude of visionary and ignorant schemers, were experimenting with every imaginable device, in the vain hope of attaining perpetual motion, and other hardly less absurd results, by its modification and improvement. Steam-engine building establishments sprang up wherever a mechanic had succeeded in erecting a workshop and in acquiring a local reputation as a worker in metal, and many of Watt's workmen went out from Soho to take charge of the work done in these shops. Nearly all of the great establishments which are to-day most noted for their extent and for the importance and magnitude of the work done in them, not only in Great Britain, but in Europe and the United States, came into existence during this second period of the application of the steam-engine as a prime mover.

The new establishments usually grew out of older shops of a less pretentious character, and were managed by men who had been trained by Watt, or who had had a still more awakening experience with those who vainly strove to make up, by their ingenuity and by great excellence of workmanship, the advantages possessed at Soho in a legal monopoly and greater experience in the business.

It was exceedingly difficult to find expert and conscientious workmen, and machine-tools had not become as thoroughly perfected as had the steam-engine itself. These difficulties were gradually overcome, however, and thenceforward the growth of the business was increasingly rapid.

Every important form of engine had now been invented. Watt had perfected, with the aid of Murdoch, both the pumping-engine and the rotative steam-engine for application to mills. He had invented the trunk engine, and Murdoch had devised the oscillating engine and the ordinary slide-valve, and had made a model locomotive-engine, while Hornblower had introduced the compound engine. The application of steam to navigation had been often proposed, and had sometimes been attempted, with sufficient success to indicate to the intelligent observer an ultimate triumph. It only remained to extend the use of steam as a motor into all known departments of industry, and to effect such improvements in details as experience should prove desirable.

The engines of Hero, of Porta, and of Branca were, it will be remembered, non-condensing; but the first plan of a non-condensing engine that could be made of any really practical use is given in the "Theatrum Machinarum" of Leupold, published in 1720. This sketch is copied in Fig. 41. It is stated by Leupold that this plan was suggested by Papin. It consists of two single-acting cylinders, *r s*, receiving steam alternately from the same steam-pipe through a "four-way cock," *x*, and exhausting into the atmosphere. Steam is furnished by the boiler, *a*, and the pistons, *c d*, are alternately raised and depressed, depressing and raising the pump-rods, *k l*, to which they are attached by the beams, *h g*, vibrating on the centres, *i i*. The water from the pumps, *o p*, is forced up the stand-pipe, *q*, and discharged at its top. The alternate action of the steam-pistons is secured by turning the "four-way cock," x, first into the position shown, and then, at the completion of the stroke, into the reverse position, by which change the steam from the

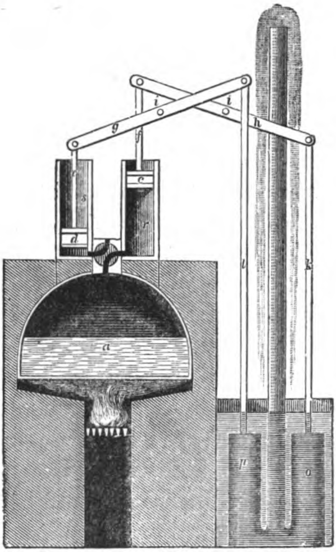


FIG. 41.—Leupold's Engine, 1720.

boiler is then led into the cylinder, s, and the steam in r is discharged into the atmosphere.[1]

Leupold states that he is indebted to Papin for the suggestion of the peculiar valve here used. He also proposed to use a Savery engine without condensation in raising water. We have no evidence that this engine was ever built.

The first rude scheme for applying steam to locomotion on land was probably that of Isaac Newton, who, in 1680, proposed the machine shown in the accompanying figure (42), which will be recognized as representing the scientific

[1] *Vide* "Theatrum Machinarum," vol. iii., Tab. 30.

toy which is found in nearly every collection of illustrative philosophical apparatus. As described in the "Explanation of the Newtonian Philosophy," it consists of a spherical boiler, *B*, mounted on a carriage. Steam issuing from the pipe, *C*, seen pointing directly backward, by its reaction upon the carriage, drives the latter ahead. The driver, sitting at *A*, controls the steam by the handle, *E*, and cock, *F*. The fire is seen at *D*.

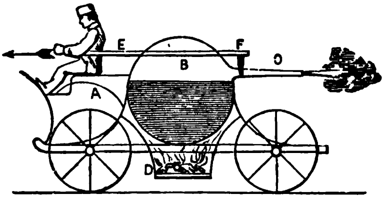


FIG. 42.—Newton's Steam-Carriage, 1680.

When, at the end of the eighteenth century, the steam-engine had been so far perfected that the possibility of its successful application to locomotion had become fully and very generally recognized, the problem of adapting it to locomotion on land was attacked by many inventors.

Dr. Robison had, as far back as in 1759, proposed it to James Watt during one of their conferences, at a time when the latter was even more ignorant than the former of the principles which were involved in the construction of the steam-engine, and this suggestion may have had some influence in determining Watt to pursue his research; thus setting in operation that train of thoughtful investigation and experiment which finally earned for him his splendid fame.

In 1765, that singular genius, Dr. Erasmus Darwin, whose celebrity was acquired by speculations in poetry and philosophy as well as in medicine, urged Matthew Boulton —subsequently Watt's partner, and just then corresponding with our own Franklin in relation to the use of steam-power —to construct a steam-carriage, or "fiery chariot," as he character of the work of the mechanic Brezin a century ago. The steam-cylinders were 13 inches in diameter, and the engine was evidently of considerable power. This locomotive was intended for the transportation of artillery. It consists of two beams of heavy timber extending from end to end, supported by two strong wheels behind, and one still heavier but smaller wheel in front. The latter carries on its rim blocks which cut into the soil as the wheel turns, and thus give greater holding power. The single wheel is turned by two single-acting engines, one on each side, supplied with steam by a boiler (seen in the sketch) suspended in front of the machine. The connection between the engines and the wheels was effected by means of pawls, as first proposed by Papin, which could be reversed when it was desired to drive the machine backward. A seat is mounted on the carriage-body for the driver, who steers the machine by a train of gearing, which turns the whole frame, carrying the machinery 15 or 20 degrees either way. This locomotive was found to have been built on a tolerably satisfactory general plan; but the boiler was too small, and the steering apparatus was incapable of handling the carriage with promptness.

The death of one of Cugnot's patrons, and the exile of the other, put an end to Cugnot's experiments.

Cugnot was a mechanic by choice, and exhibited great talent. He was a native of Vaud, in Lorraine, where he was born in 1725. He served both in the French and the German armies. While under the Maréchal de Saxe, he constructed his first steam locomotive-engine, which only disappointed him, as he stated, in consequence of the inefficiency of the feed-pumps. The second was that built under the authority of the Minister Choiseul, and cost 20,000 livres. Cugnot received from the French Government a pension of 600 livres. He died in 1804, at the age of seventy-nine years.

Watt, at a very early period, proposed to apply his own engine to locomotion, and contemplated using either a non-condensing engine or an air-surface condenser. He actually included the locomotive-engine in his patent of 1784; and his assistant, Murdoch, in the same year, made a working-model locomotive (Fig. 45), which was capable of running at a rapid rate. This model, now deposited in the Patent Museum at South Kensington, London, had a flue-boiler, and its steam-cylinder was three-fourths of an inch in diameter, and the stroke of piston 2 inches. The driving-wheels were 9½ inches diameter.

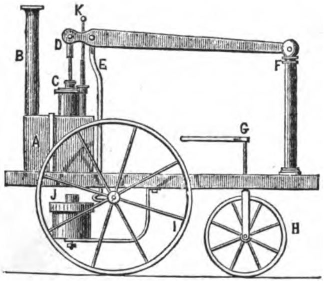


Fig. 45.—Murdoch's Model, 1784.

Nothing was, however, done on a larger scale by either Watt or Murdoch, who both found more than enough to claim their attention in the construction and introduction of other engines. Murdoch's model is said to have run from 6 to 8 miles an hour, its little driving-wheels making from 200 to 275 revolutions per minute. As is seen in the sketch, this model was fitted with the same form of engine, known as the "grasshopper-engine," which was used in the United States by Oliver Evans.

"To Oliver Evans," says Dr. Ernest Alban, the distinguished German engineer, "was it reserved to show the true value of a long-known principle, and to establish thereon a new and more simple method of applying the power of steam—a method that will remain an eternal memorial to its introducer." Dr. Alban here refers to the earliest permanently successful introduction of the non-condensing high-pressure steam-engine.

Oliver Evans, one of the most ingenious mechanics that America has ever produced, was born at Newport, Del., in 1755 or 1756, the son of people in very humble circumstances.

Oliver Evans.

He was, in his youth, apprenticed to a wheelwright, and soon exhibited great mechanical talent and a strong desire to acquire knowledge. His attention was, at an early period, drawn to the possible application of the power of steam to useful purposes by the boyish pranks of one of his comrades, who, placing a small quantity of water in a gun-barrel, and ramming down a tight wad, put the barrel in the fire of a blacksmith's forge. The loud report which parallelogram"—a kind of parallel-motion very similar to one of those designed by Watt. In the sketch (Fig. 46), 2 is the crank, 3 the valve-motion, 4 the steam-pipe from the boiler, *E*, 5 6 7 the feed-pipe leading from the pump, *F*. *A* is the boiler. The flame from the fire on the grate, *H*, passes under the boiler between brick walls, and back through a central flue to the chimney, *I*.

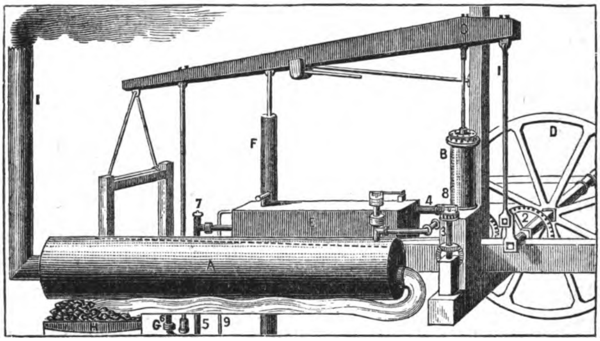


FIG. 46.—Evans's Non-condensing Engine, 1800.

Subsequently, Evans continued to extend the applications of his engine and to perfect its details; and, others following in his track, the non-condensing engine is to-day fulfilling the predictions which he made 70 years ago, when he said:

"I have no doubt that my engines will propel boats against the current of the Mississippi, and wagons on turnpike roads, with great profit. . . ."

"The time will come when people will travel in stages moved by steam-engines from one city to another, almost as fast as birds can fly, 15 or 20 miles an hour. . . . A carriage will start from Washington in the morning, the passengers will breakfast at Baltimore, dine at Philadelphia, and sup in New York the same day. . . .

"Engines will drive boats 10 or 12 miles an hour, and

and placed in competition with 10 wagons drawn by 5 horses each.

In the sketch above given of the "Oruktor Amphibolis," the engine is seen to resemble that previously described. The wheel, *A*, is driven by a rod depending from the end of a beam, *B′B*, the other end of which is supported at *E* by the frame, *E F G*. The body of the machine is carried on wheels, *K K*, driven by belts, *M M*, from the pulley on the shaft carrying *A*. The paddle-wheel is seen at *W*. Evans had some time previously sent Joseph Sampson to England with copies of his plans, and by him they were shown to Trevithick, Vivian, and other British engineers.

Among other devices, the now familiar Cornish boiler, having a single internal flue, and the Lancashire boiler, having a pair of internal flues, were planned and used by Evans.

At about the time that he was engaged on his steam dredging-machine, Evans communicated with Messrs. McKeever & Valcourt, who contracted with him to build an engine for a steam-vessel to ply between New Orleans and Natchez on the Mississippi, the hull of the vessel to be built on the river, and the machinery to be sent to the first-named city to be set up in the boat. Financial difficulties and low water combined to prevent the completion of the steamer, and the engine was set at work driving a saw-mill, where, until the mill was destroyed by fire, it sawed lumber at the rate of 250 feet of boards per hour.

Evans never succeeded in accomplishing in America as great a success as had rewarded Watt in Great Britain; but he continued to build steam-engines to the end of his life, April 19, 1819, and was succeeded by his sons-in-law, James Rush and David Muhlenberg.

He exhibited equal intelligence and ingenuity in perfecting the processes of milling, and in effecting improvements in his own business, that of the millwright. When but twenty-four years old, he invented a machine for making the wire teeth used in cotton and woolen cards, turning them out at the rate of 3,000 per minute. A little later he invented a card-setting machine, which cut the wire from the reel, bent the teeth, and inserted them. In milling, he invented a whole series of machines and attachments, including the elevator, the "conveyor," the "hopper-box," the "drill," and the "descender," and enabled the miller to make finer flour, gaining over 20 pounds to the barrel, and to do this at half the former cost of attendance. The introduction of his improvements into Ellicott's mills, near Baltimore, where 325 barrels of flour were made per day, was calculated to have saved nearly $5,000 per year in cost of labour, and over $30,000 by increasing the production. He wrote "The Young Steam-Engineer's Guide," and a work which remained standard many years after his death, "The Young Millwright's Guide." Less fortunate than his transatlantic rival, he was nevertheless equally deserving of fame. He has sometimes been called "The Watt of America."

The application of steam to locomotion on the common road was much more successful in Great Britain than in the United States. As early as 1786, William Symmington, subsequently more successful in his efforts to introduce steam for marine propulsion, assisted by his father, made a working model of a steam-carriage, which did not, however, lead to important results.

In 1802, Richard Trevithick, a pupil of Murdoch's, who afterward became well known in connection with the introduction of railroads, made a model steam-carriage, which was patented in the same year. The model may still be seen in the Patent Museum at South Kensington.[1]

In this engine, high-pressure steam was employed, and the condenser was dispensed with. The boiler was of the form devised by Evans, and was subsequently generally

---

[1] *See* "Life of Trevithick."

used in Cornwall, where it was called the "Trevithick Boiler." The engine had but one cylinder, and the piston-rod drove a "cross-tail," working in guides, which was connected with a "cross-head" on the opposite side of the shaft by two "side-rods." The connecting-rod was attached to the cross-head and the crank, "returning" toward the cylinder as the shaft lay between the latter and the cross-head. This was probably the first example of the now common "return connecting-rod engine." The connection between the crank-shaft and the wheels of the carriage was effected by gearing. The valve-gear and the feed-pumps were worked from the engine-shaft. The inventor proposed to secure his wheels against slipping by projecting bolts, when necessary, through the rim of the wheel into the ground. The first carriage of full size was built by Trevithick and Vivian at Camborne, in 1803, and, after trial, was taken to London, where it was exhibited to the public. *En route*, it was driven by its own engines to Plymouth, 90 miles from Camborne, and then shipped by water. It is not known whether the inventor lost faith in his invention; but he very soon dismantled the machine, sold the engine and carriage separately, and returned to Cornwall, where he soon began work on a railroad-locomotive.

In 1821, Julius Griffiths, of Brompton, Middlesex, England, patented a steam-carriage for the transportation of passengers on the highway. His first road-locomotive was built in the same year by Joseph Bramah, one of the ablest mechanics of his time. The frame of the carriage carried a large double coach-body between the two axles, and the machinery was mounted over and behind the rear axle. One man was stationed on a rear platform, to manage the engine and to attend to the fire, and another, stationed in front of the body of the coach, handled the steering-wheel. The boiler was composed of horizontal water-tubes and steam-tubes, the latter being so situated as to receive heat from the furnace-gases *en route* to the chimney, and thus to act as a superheater. The wheels were driven, by means of intermediate gearing, by two steam-engines, which, with their attachments, were suspended on helical springs, to prevent injury by jars and shocks. An air-surface condenser was used, consisting of flattened thin metal tubes, cooled by the contact of the external air, and discharging the water of condensation, as it accumulated within them, into a feed-pump, which, in turn, forced it into the lowest row of tubes in the boiler.

The boiler did not prove large enough for continuous work ; but the carriage was used experimentally, now and then, for a number of years.

During the succeeding ten years the adaptation of the steam-engine to land-transportation continued to attract more and more attention, and experimental road-engines were built with steadily-increasing frequency. The defects of these engines revealing themselves on trial, they were one by one remedied, and the road-locomotive gradually assumed a shape which was mechanically satisfactory. Their final introduction into general use seemed at one time only a matter of time ; their non-success was due to causes over which the legislator and the general public, and not the engineer, had control, as well as to the development of steam-transportation on a rival plan.

In 1822, David Gordon patented a road-engine, but it is not known whether it was ever built. At about the same time, Mr. Goldsworthy Gurney, who subsequently took an active part in their introduction, stated, in his lectures, that "elementary power is capable of being applied to propel carriages along common roads with great political advantage, and the floating knowledge of the day places the object within reach." He made an ammonia-engine—probably the first ever made—and worked it so successfully, that he made use of it in driving a little locomotive.

Two years later, Gordon patented a curious arrangement, which, however, had been proposed twelve years earlier by

Brunton, and was again proposed afterward by Gurney, and others. This consisted in fitting to the engine a set of jointed legs, imitating, as nearly as the inventor could make them, the action of a horse's legs and feet. Such an arrangement was actually experimented with until it was found that they could not be made to work satisfactorily, when it was also found that they were not needed.

During the same season, Burstall & Hill made a steam-carriage, and made many unsuccessful attempts to introduce their plan. The engine used was like that of Evans, except that the steam-cylinder was placed at the end of the beam, and the crank-shaft under the middle. The front and rear wheels were connected by a longitudinal shaft and bevel gearing. The boiler was found to have the usual defect, and would only supply steam for a speed of three or four miles an hour. The result was a costly failure. W. H. James, of London, in 1824–'25, proposed several devices for placing the working parts, as well as the body of the carriage, on springs, without interfering with their operation, and the Messrs. Seaward patented similar devices. Samuel Brown, in 1826, introduced a gas-engine, in which the piston was driven by the pressure produced by the combustion of gas, and a vacuum was secured by the condensation of the resulting vapour. Brown built a locomotive which he propelled by this engine. He ascended Shooter's Hill, near London, and the principal cause of his ultimate failure seems to have been the cost of operating the engine.

From this date forward, during several years, a number of inventors and mechanics seem to have devoted their whole time to this promising scheme. Among them, Burstall & Hill, Gurney, Ogle & Summers, Sir Charles Dance, and Walter Hancock, were most successful.

Gurney, in the year 1827, built a steam-carriage, which he kept at work nearly two years in and about London, and sometimes making long journeys. On one occasion he made the journey from Meksham to Cranford Bridge, a distance boilers" did excellent service on Hancock's steam-carriages, where experience showed that there was little or no danger of disruptive explosions.

Hancock's first steam-carriage was mounted on three wheels, the leading-wheel arranged to swivel on a king-bolt, and driven by a pair of oscillating cylinders connected with its axle, which was "cranked" for the purpose. The engines turned with the steering-wheel. This carriage was by no means satisfactory, but it was used for a long time, and traveled many hundreds of miles without once failing to do the work assigned it.

By this time there were a half-dozen steam-carriages under construction for Hancock, for Ogle & Summers, and for Sir Charles Dance.

In 1831, Hancock placed a new carriage on a route between London and Stratford, where it ran regularly for hire. Dance, in the same season, started another on the line between Cheltenham and Gloucester, where it ran from February 21st to June 22d, traveling 3,500 miles and carrying 3,000 passengers, running the 9 miles in 55 minutes usually, and sometimes in three-quarters of an hour, and never meeting with an accident, except the breakage of an axle in running over heaps of stones which had been purposely placed on the road by enemies of the new system of transportation. Ogle & Summers's carriage attained a speed, as testified by Ogle before a committee of the House of Commons, of from 32 to 35 miles an hour, and on a rising grade, near Southampton, at 24½ miles per hour. They carried 250 pounds of steam, ran 800 miles, and met with no accident. Colonel Macerone, in 1833, ran a steam-carriage of his own design from London to Windsor and back, with 11 passengers, a distance of 23½ miles, in 2 hours. Sir Charles Dance, in the same year, ran his carriage 16 miles an hour, and made long excursions at the rate of 9 miles an hour. Still another experimenter, Heaton, ascended Lickey Hill, between Worcester and Birmingham, on gradients of wheels, *S*, are thus driven. A blower, *T*, gives a forced draught. The driver sits at *M*, steering by the wheel, *N*, which is coupled to the larger wheel, *P*, and thus turns the forward axle into any desired position. In 1834, Hancock built a steam "drag" on an Austrian order, which, carrying 10 persons and towing a coach containing 6 passengers, was driven through the city beyond Islington, making 14 miles an hour on a level, and 8 miles or more on rising ground. In the same year he built the "Era," and, in August, put the "Autopsy" on with it, to make a steam-line to Paddington. These coaches ran until the end of November, carrying 4,000 passengers, at a usual rate of speed of 12 miles per hour. He then sent the "Era" to Dublin, where, on one occasion, it ran 18 miles per hour.

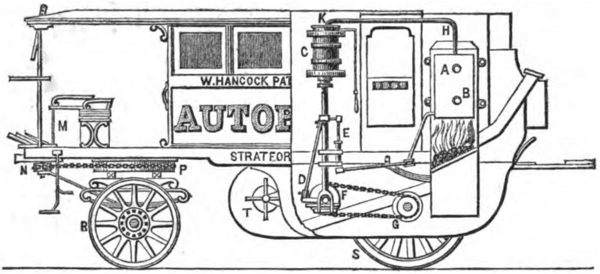


FIG. 49.—Hancock's "Autopsy," 1833.

In 1835 a large carriage, the "Erin," was completed, which was intended to carry 20 passengers. It towed three omnibuses and a stage-coach, with 50 passengers, on a level road, at the speed of 10 miles an hour. It drew an omnibus with 18 passengers through Whitehall, Charing Cross, and Regent Street, and out to Brentford, running 14 miles an hour. It ran also to Reading, making 38 miles, with the same load, in 3 hours and 8 minutes running time. The stops *en route* occupied a half-hour. The same carriage made 75 miles to Marlborough in 7½ hours running time, stopping 4½ hours on the road, in consequence of having left the tender and supplies behind.

In May, 1836, Hancock put all his carriages on the Paddington road, and ran regularly for over five months, running 4,200 miles in 525 trips to Islington, 143 to Paddington, and 44 to Stratford, passing through the city over 200 times. The carriages averaged 5 hours and 17 or 18 minutes daily running time. A light steam-phaeton, built in 1838, for his own use, made 20 miles an hour, and was driven about the city, and among horses and carriages, without causing annoyance or danger. Its usual speed was about 10 miles an hour. Altogether, Hancock built nine steam-carriages, capable of carrying 116 passengers in addition to the regular attendants.[1]

In December, 1833, about 20 steam-carriages and traction road-engines were running, or were in course of construction, in and near London. In our own country, the roughness of roads discouraged inventors; and in Great Britain even, the successful introduction of road-locomotives, which seemed at one time almost an accomplished fact, finally met with so many obstacles, that even Hancock, the most ingenious, persistent, and successful constructor, gave up in despair. Hostile legislation procured by opposing interests, and the rapid progress of steam-locomotion on railroads, caused this result.

In consequence of this interruption of experiment, almost nothing was done during the succeeding quarter of a century, and it is only within a few years that anything like a business success has been founded upon the construction of road-locomotives, although the scheme seems to have been at no time entirely given up.

The opposition of coach-proprietors, and of all classes having an interest in the old lines of coaches, was most de-

---

[1] For a detailed account of the progress of steam on the highway, *see* "Steam on Common Roads," etc., by Young, Holley, & Fisher, London, 1861.

neers of the time, testified that he considered the practicability of such a system as fully established, and that the result would be its general adoption. Gurney had run his carriage between 20 and 30 miles an hour; Hancock could sustain a speed of 10 miles; Ogle had run his coach 32 to 35 miles an hour, and ascended a hill rising 1 in 6 at the speed of 24½ miles. Summers had traveled up a hill having a gradient of 1 in 12, with 19 passengers, at the rate of speed of 15 miles per hour; he had run 4½ hours at 30 miles an hour. Farey thought that steam-coaches would be found to cost one-third as much as the stage-coaches in use. The steam-carriages were reported to be safer than those drawn by horses, and far more manageable; and the construction of boilers adopted—the "sectional" boiler, as it is now called—completely insured against injury by explosion, and the dangers and inconveniences arising from the frightening of horses had proved to be largely imaginary. The wear and tear of roads were found to be less than with horses, while with broad wheel-tires the carriages acted beneficially as road-rollers. The committee finally concluded:

"1. That carriages can be propelled by steam on common roads at an average rate of 10 miles per hour.

"2. That at this rate they have conveyed upward of 14 passengers.

"3. That their weight, including engine, fuel, water, and attendants, may be under three tons.

"4. That they can ascend and descend hills of considerable inclination with facility and safety.

"5. That they are perfectly safe for passengers.

"6. That they are not (or need not be, if properly constructed) nuisances to the public.

"7. That they will become a speedier and cheaper mode of conveyance than carriages drawn by horses.

"8. That, as they admit of greater breadth of tire than other carriages, and as the roads are not acted on so injuriously as by the feet of horses in common draught, such carriages will cause less wear of roads than coaches drawn by horses.

"9. That rates of toll have been imposed on steam-carriages, which would prohibit their being used on several lines of road, were such charges permitted to remain unaltered."

THE RAILROAD, which now, by the adaptation of steam to the propulsion of its carriages, became the successful rival of the system of transportation of which an account has just been given, was not a new device. It, like all other important changes of method and great inventions, had been growing into form for ages. The ancients were accustomed to lay down blocks of stone as a way upon which their heavily-loaded wagons could be drawn with less resistance than on the common road. This practice was gradually so modified as to result in the adoption of the now universally-practised methods of paving and road-making. The old tracks, bearing the marks of heavy traffic, are still seen in the streets of the unearthed city of Pompeii.

In the early days of mining in Great Britain, the coal or the ore was carried from the mine to the vessel in which it was to be embarked in sacks on the backs of horses. Later, the miners laid out wagon-roads, and used carts and wagons drawn by horses, and the roads were paved with stone along the lines traversed by the wheels of the vehicles. Still later (about 1630), heavy planks or squared timber took the place of the stone, and were introduced into the north of England by a gentleman of the name of Beaumont, who had transferred his property there from the south. A half century later, the system had become generally introduced. By the end of the eighteenth century the construction of these "tram-ways" had become well-understood, and the economy which justified the expenditure of considerable amounts of money in making cuts and in filling, to bring the road to a uniform grade, had become well-recognized. Arthur Young, writing at this time, says the who, in consequence of the unobtrusive manner in which his work was done, has never received the full credit to which he is entitled.

Colonel John Stevens, of Hoboken, as he is generally called, was born in the city of New York, in 1749; but throughout his business-life he was a resident of New Jersey.

His attention is said to have been first called to the application of steam-power by seeing the experiments of John Fitch with his steamer on the Delaware, and he at once devoted himself to the introduction of steam-navigation with characteristic energy, and with a success that will be indicated when we come to the consideration of that subject.

Colonel John Stevens.

But this far-sighted engineer and statesman saw plainly roads would offer but little resistance ; and places the whole subject before the public with such accuracy of statement and such evident appreciation of its true value, that every one who reads this remarkable document will agree fully with President Charles King, who said[1] that "whosoever shall attentively read this pamphlet, will perceive that the political, financial, commercial, and military aspects of this great question were all present to Colonel Stevens's mind, and that he felt that he was fulfilling a patriotic duty when he placed at the disposal of his native country these fruits of his genius. The offering was not then accepted. The 'Thinker' was ahead of his age ; but it is grateful to know that he lived to see his projects carried out, though not by the Government, and that, before he finally, in 1838, closed his eyes in death, at the great age of eighty-nine, he could justly feel assured that the name of Stevens, in his own person and in that of his sons, was imperishably enrolled among those which a grateful country will cherish."

Without having made any one superlatively great improvement in the mechanism of the steam-engine, like that which gave Watt his fame—without having the honour even of being the first to propose the propulsion of vessels by the modern steam-engine, or steam-transportation on land—he exhibited a far better knowledge of the science and the art of engineering than any man of his time ; and he entertained and urged more advanced opinions and more statesmanlike views in relation to the economical importance of the improvement and the application of the steam-engine, both on land and water, than seem to be attributable to any other leading engineer of that time.

Says Dr. King : "Who can estimate if, at that day, acting upon the well-considered suggestion of President Madison, 'of the signal advantages to be derived to the United States from a general system of internal communication and

---

[1] "Progress of the City of New York."

conveyance,' Congress had entertained Colonel Stevens's proposal, and, after verifying by actual experiment upon a small scale the accuracy of his plan, had organized such a 'general system of internal communication and conveyance;' who can begin to estimate the inappreciable benefits that would have resulted therefrom to the comfort, the wealth, the power, and, above all, to the absolutely impregnable union of our great Republic and all its component parts? All this Colonel Stevens embraced in his views, for he was a statesman as well as an experimental philosopher; and whoever shall attentively read his pamphlet, will perceive that the political, financial, commercial, and military aspects of this great question were all present to his mind, and he felt that he was fulfilling a patriotic duty when he placed at the disposal of his native country these fruits of his genius."

WILLIAM HEDLEY, who has already been referred to, seems to have been the first to show, by carefully-conducted experiment, how far the adhesion of the wheels of the locomotive-engine could be relied upon for hauling-power in the transportation of loads.

His employer, Blackett, had applied to Trevithick for a locomotive-engine to haul coal-trains at the Wylam collieries; but Trevithick was unable, or was disinclined, to build him one, and in October, 1812, Hedley was authorized to attempt the construction of an engine. It was at about this time that Blenkinsop (1811) was trying the toothed rail or rack, the Messrs. Chapman (December, 1812) were experimenting with a towing-chain, and (May, 1813) Brunton with movable legs.

Hedley, who had known of the success met with in the experiments of Trevithick with smooth wheels hauling loads of considerable weight, in Cornwall, was confident that equal success might be expected in the north-country, and built a carriage to be moved by men stationed at four handles, by which its wheels were turned.

This carriage was loaded with heavy masses of iron, and attached to trains of coal-wagons on the railway. By repeated experiment, varying the weight of the traction-carriage and the load hauled, Hedley ascertained the proportion of the weight required for adhesion to that of the loads drawn. It was thus conclusively proven that the weight of his proposed locomotive-engine would be sufficient to give the pulling-power necessary for the propulsion of the coal-trains which it was to haul.

When the wheels slipped in consequence of the presence of grease, frost, or moisture on the rail, Hedley proposed to sprinkle ashes on the track, as sand is now distributed from the sand-box of the modern engine. This was in October, 1812.

Hedley now went to work building an engine with smooth wheels, and patented his design March 13, 1813, a month after he had put his engine at work. The locomotive had a cast-iron boiler, and a single steam-cylinder 6 inches in diameter, with a small fly-wheel. This engine had too small a boiler, and he soon after built a larger engine, with a return-flue boiler made of wrought-iron. This hauled 8 loaded coal-wagons 5 miles an hour at first, and a little later 10, doing the work of 10 horses. The steam-pressure was carried at about 50 pounds, and the exhaust, led into the chimney, where the pipe was turned upward, thus secured a blast of considerable intensity in its small chimney. Hedley also contracted the opening of the exhaust-pipe to intensify the blast, and was subjected to some annoyance by proprietors of lands along his railway, who were irritated by the burning of their grass and hedges, which were set on fire by the sparks thrown out of the chimney of the locomotive. The cost of Hedley's experiment was defrayed by Mr. Blackett.

Subsequently, Hedley mounted his engine on eight wheels, the four-wheeled engines having been frequently stopped by breaking the light rails then in use. Hedley's ing his parents comfortable, and then returned to his old station as brakeman at the pit.

Here he made some useful improvements in the arrangement of the machinery, and spent his spare hours in studying his engine and planning new machines. He a little later distinguished himself by altering and repairing an old Newcomen engine at the High Pit, which had failed to give satisfaction, making it thoroughly successful after three days' work. The engine cleared the pit, at which it had been vainly laboring a long time, in two days after Stephenson started it up.

In the year 1812, Stephenson was made engine-wright of the Killingworth High Pit, receiving £100 a year, and it was made his duty to supervise the machinery of all the collieries under lease by the so-called "Grand Allies." It was here, and at this period, that he commenced a systematic course of self-improvement and the education of his son, and here he first began to be recognized as an inventor. He was full of life and something of a wag, and often made most amusing applications of his inventive powers : as when he placed the watch, which a comrade had brought him as out of repairs, in the oven "to cook," his quick eye having noted the fact that the difficulty arose simply from the clogging of the wheels by the oil, which had been congealed by cold.

Smiles,[1] his biographer, describes his cottage as a perfect curiosity-shop, filled with models of engines, machines of various kinds, and novel apparatus. He connected the cradles of his neighbours' wives with the smoke-jacks in their chimneys, and thus relieved them from constant attendance upon their infants; he fished at night with a submarine lamp, which attracted the fish from all sides, and gave him wonderful luck; he also found time to give colloquial instruction to his fellow-workmen.

---

[1] "Lives of George and Robert Stephenson," by Samuel Smiles. New York and London, 1868.

Sir Humphry Davy, independently and almost simultaneously, invented the "safety-lamp," without which few mines of bituminous coal could to-day be worked. The former used small tubes, the latter fine wire gauze, to intercept the flame. Stephenson proved the efficiency of his lamp by going with it directly into the inflammable atmosphere of a dangerous mine, and repeatedly permitting the light to be extinguished when the lamp became surcharged with the explosive mixture which had so frequently proved fatal to the miners. This was in October and November, 1815, and Stephenson's work antedates that of the great philosopher.[1] The controversy which arose between the supporters of the rival claims of the two inventors was very earnest, and sometimes bitter. The friends of the young engineer raised a subscription, amounting to above £1,000, and presented it to him as a token of their appreciation of the value of his simple yet important contrivance. Of the two forms of lamp, that of Stephenson is claimed to be safest, the Davy lamp being liable to produce explosions by igniting the explosive gas when, by its combustion within the gauze cylinder, the latter is made red-hot. Under similar conditions, the Stephenson lamp is simply extinguished, as was seen at Barnsley, in 1857, at the Oaks Colliery, where both kinds of lamp were in use, and elsewhere.

Stephenson continued to study and experiment, with a view to the improvement of his locomotive and the railroad. He introduced better methods of track-laying and of jointing the rails, adopting a half-lap, or peculiar scarf-joint, in place of the then usual square-butt joint. He patented, with these modifications of the permanent way, several of his improvements of the engine. He had substituted forged for the rude cast wheels previously used,[2] and had

---

[1] *Vide* "A Description of the Safety-Lamp invented by George Stephenson," etc., London, 1817.

[2] The American chilled wheel of cast-iron, a better wheel than that above described, has never been generally and successfully introduced in Europe.

cow were to stray upon the line and get in the way of the engine, would not that be a very awkward circumstance?" replied, "Yes, *very* awkward—*for the coo!*" And when asked if men and animals would not be frightened by the red-hot smoke-pipe, answered, "But how would they know that it was not *painted?*" The line was finally built, with George Rennie as consulting, and Stephenson as principal constructing engineer.

His work on this road became one of the important elements of the success, and one of the great causes of the distinction, which marked the life of these rising engineers. The successful construction of that part of the line which lay across "Chat Moss," an unfathomable swampy deposit of peat, extending over an area of 12 square miles, and the building of which had been repeatedly declared an impossibility, was in itself sufficient to prove that the engineer who had accomplished it was no common man. Stephenson adopted the very simple yet bold expedient of using, as a filling, compacted turf and peat, and building a road-bed of materials lighter than water, or the substance composing the bog, and thus forming a *floating* embankment, on which he laid his rails. To the surprise of every one but Stephenson himself, the plan proved perfectly successful, and even surprisingly economical, costing but little more than one-tenth the estimate of at least one engineer. Among the other great works on this remarkable pioneer-line were the tunnel, a mile and a half long, from the station at Liverpool to Edgehill; the Olive Mount deep-cut, two miles long, and in some places 100 feet deep, through red sandstone, of which nearly 500,000 yards were removed; the Sankey Viaduct, a brick structure of nine arches, of 50 feet span each, costing £45,000; and a number of other pieces of work which are noteworthy in even these days of great works.

Stephenson planned all details of the line, and even designed the bridges, machinery, engines, turn-tables, switches,

4. The engine and boiler must be supported on springs, and rest on 6 wheels, the height of the whole not exceeding 15 feet to the top of the chimney.

5. The engine, with water, must not weigh more than 6 tons; but an engine of less weight would be preferred, on its drawing a proportionate load behind it; if of only 4½ tons, then it might be put only on 4 wheels. The company to be at liberty to test the boiler, etc., by a pressure of 150 pounds to the square inch.

6. A mercurial gauge must be affixed to the machine, showing the steam-pressure above 45 pounds to the square inch.

7. The engine must be delivered, complete and ready for trial, at the Liverpool end of the railway, not later than the 1st of October, 1829.

8. The price of the engine must not exceed £550.

This circular was printed and published throughout the kingdom, and a considerable number of engines were constructed to compete at the trial, which was proposed to take place October 1, 1829, but which was deferred to the 6th of that month. Only four engines, however, were finally entered on the day of the trial. These were the "Novelty," constructed by Messrs. Braithwaite & Ericsson, the latter being the distinguished engineer who subsequently came to the United States to introduce screw-propulsion, and, later, the monitor system of iron-clads; the "Rocket," built from Stephenson's plans; and the "Sanspareil" and the "Perseverance," built by Hackworth and Burstall, respectively.

The "Sanspareil," which was built under the direction of Timothy Hackworth, one of Stephenson's earlier foremen, resembled the engine built by the latter for the Stockton & Darlington road, but was heavier than had been stipulated, was not ready for work when called, and, when finally set at work, proved to be very extravagant in its use of fuel, partly in consequence of the extreme intensity of its blast, which caused the expulsion of unconsumed coals from the furnace.

The "Perseverance" could not attain the specified speed, and was withdrawn.

total length of the boiler was 6 feet, its diameter 40 inches. The fire-box was attached to the rear of the boiler, and was 3 feet high and 2 feet wide, with water-legs to protect its side-sheets from injury by overheating. The cylinders, as seen in the sketch, were inclined, and coupled to a single pair of driving-wheels. A tender, attached to the engine, carried the fuel and water. The engine weighed less than 4½ tons.

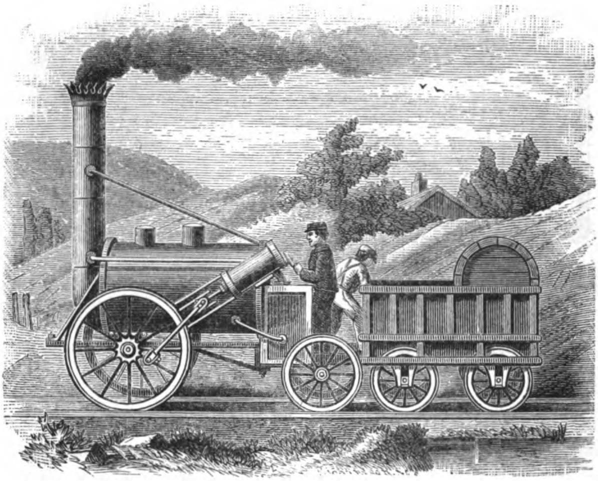


FIG. 55.—The "Rocket," 1829.

The little engine does not seem to have been very prepossessing in appearance, and the "Novelty" is said to have been the general favourite, the Stephenson engine having few, if any, backers among the spectators. On its first trial, it ran 12 miles in less than an hour.

After the accident which disabled the "Novelty," the "Rocket" came forward again, and ran at the rate of from 25 to 30 miles an hour, drawing a single carriage carrying 30 passengers. Two days later, on the 8th of October, steam was raised in a little less than an hour from cold water, and church of Clay Cross, and this noble system of support, are together a nobler monument than any statue or similar structure could be.

The character of George Stephenson was in every way admirable. Simple, earnest, and honourable; courageous, indomitable, and industrious; humourous, kind, and philanthropic, his memory will long be cherished, and will long prove an incentive to earnest effort and to the pursuit of an honourable fame with hundreds of the youth who, reading his simple yet absorbing story, as told by his biographer, shall in later years learn to know him.

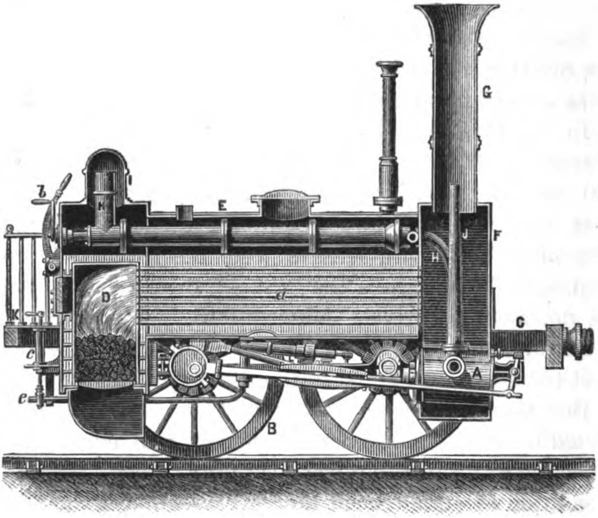


FIG. 57.—Stephenson's Locomotive, 1833.

After the death of his father, Robert Stephenson continued, as he had already done for several years, to conduct the business of building locomotives, as well as of constructing railroads. The work of locomotive engine-building was done at Newcastle, and for many years those works were the principal engine-building establishment of the world.

promptly accomplished. Under the direction of Pierre Simon, an enterprising and well-informed young engineer, who had become known principally as an advocate of the even then familiar project of a canal across the Isthmus of Darien, very complete plans of railroad communication for the kingdom were prepared, in compliance with a decree dated July 31, 1834, and were promptly authorized. The road between Brussels and Mechlin was opened May 6, 1837, and other roads were soon built; and the railway system of Belgium was the first on the Continent of Europe.

The first German railroad worked with locomotive steam-engines was that between Nuremberg and Fürth, built under the direction of M. Denis. The other European countries soon followed in this rapid march of improvement.

In the United States, public attention had been directed to this subject, as has already been stated, very early in the present century, by Evans and Stevens. At that time the people of the United States, as was natural, closely watched every important series of events in the mother-country; and so remarkable and striking a change as that which was taking place in the time of Stephenson, in methods of communication and transportation, could not fail to attract general attention and awaken universal interest.

Notwithstanding the success of the early experiments of Evans and others, and in spite of the statesman-like arguments of Stevens and Dearborn, and the earnest advocacy of the plan by all who were familiar with the revelations which were daily made of the power and capabilities of the steam-engine, it was not until after the opening of the Manchester & Liverpool road that any action was taken looking to the introduction of the locomotive. Colonel John Stevens, in 1825, had built a small locomotive, which he had placed on a circular railway before his house—now Hudson Terrace—at Hoboken, to prove that his statements had a basis of fact. This engine had two "lantern" tubular boilers, each composed of small iron tubes, arranged vertically in circles about the furnaces.[1] This exhibition had no other effect, however, than to create some interest in the subject, which aided in securing a rapid adoption of the railroad when once introduced.

The first line of rails in the New England States is said to have been laid down at Quincy, Mass., from the granite quarry to the Neponset River, three miles away, in 1826 and 1827. That between the coal-mines of Mauch Chunk, Pa., and the river Lehigh, nine miles distant, was built in 1827. In the following year the Delaware & Hudson Canal Company built a railroad from their mines to the termination of the canal at Honesdale. These roads were worked either by gravity or by horses and mules.

The competition at Rainhill, on the Liverpool and Manchester Railroad, had been so widely advertised, and promised to afford such conclusive evidence relative to the value of the locomotive steam-engine and the railroad, that engineers and others interested in the subject came from all parts of the world to witness the trial. Among the strangers present were Mr. Horatio Allen, then chief-engineer of the Delaware & Hudson Canal Company, and Mr. E. L. Miller, a resident of Charleston, S. C., who went from the United States for the express purpose of seeing the new machines tested.

Mr. Allen had been authorized to purchase, for the company with which he was connected, three locomotives and the iron for the road, and had already shipped one engine to the United States, and had set it at work on the road. This engine was received in New York in May, 1829, and its trial took place in August at Honesdale, Mr. Allen himself driving the engine. But the track proved too light for the locomotive, and it was laid up and never set at regular work. This engine was called the "Stourbridge Lion"; it was built by Foster, Rastrick & Co., of Stourbridge, Eng-

---

[1] One of these sectional boilers is still preserved in the lecture-room of the author, at the Stevens Institute of Technology.

the "Atlantic"—was set at work in September, 1832, and hauled 50 tons from Baltimore 40 miles, over gradients having a maximum rise of 37 feet to the mile, and on curves having a minimum radius of 400 feet, at the rate of 12 to 15 miles an hour. This engine weighed 6½ tons, carried 50 pounds of steam—a pressure then common on both continents—and burned a ton of anthracite coal on the round trip. The blast was secured by a fan, and the valve-gear was worked by cams instead of eccentrics. This engine made the round trip at a cost of $16, doing the work of 42 horses, which had cost $33 per trip. The engine cost $4,500, and was designed by Phineas Davis, assisted by Ross Winans.

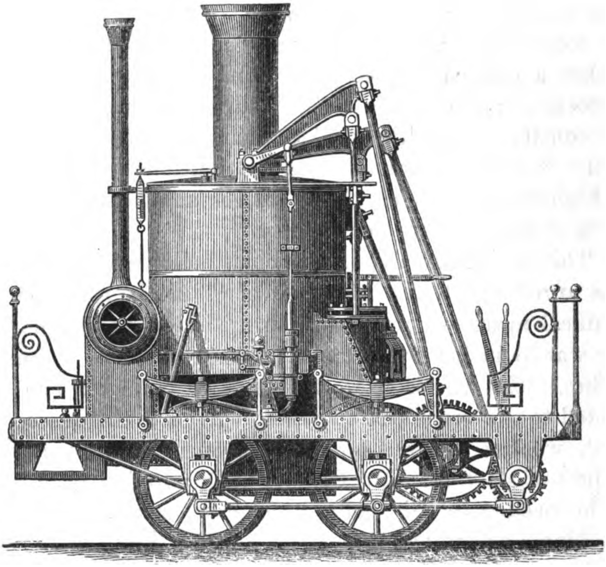


FIG. 59.—The "Atlantic," 1832.

Mr. Miller, on his return from the Liverpool & Manchester trial, ordered a locomotive for the Charleston & Hamburg Railroad from the West Point Foundery. This

A second engine (Fig. 61) was built for this road, at the West Point Foundery, from plans furnished by Horatio Allen, and was received and set at work early in the spring of 1831. The engine, called the "West Point," had a horizontal tubular boiler, but was in other respects very similar to the "Best Friend." It is said to have done very good work.

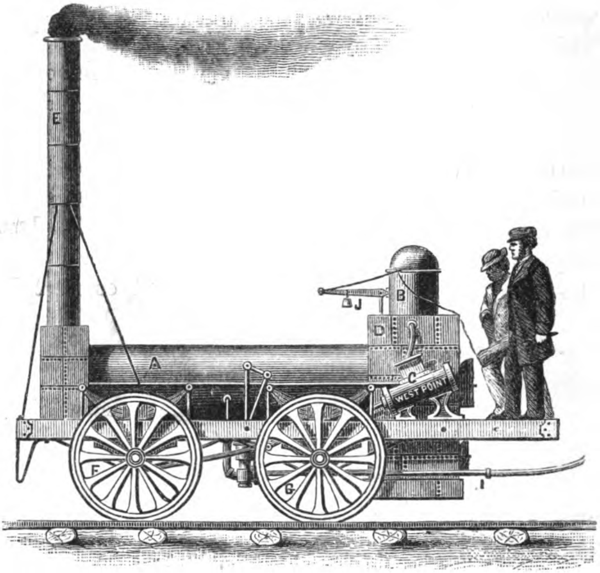


FIG. 61.—The "West Point," 1831.

The Mohawk & Hudson Railroad ordered an engine at about this time, also, of the West Point Foundery, and the trials, made in July and August, 1831, proved thoroughly successful.

This engine, the "De Witt Clinton," was contracted for by John B. Jervis, and fitted up by David Matthew. It had two steam-cylinders, each 5½ inches in diameter and 16 inches stroke of piston. The connecting-rods were directly attached to a cranked axle, and turned four coupled wheels 4½ feet in diameter. These wheels had cast-iron hubs and wrought-iron spokes and tires. The tubes were of copper, 2½ inches in diameter and 6 feet long. The engine weighed 3½ tons, and hauled 5 cars at the rate of 30 miles an hour.

Another engine, the "South Carolina" (Fig. 62), was designed by Horatio Allen for the South Carolina Railroad, and completed late in the year 1831. This was the first eight-wheeled engine, and the prototype, also, of a peculiar and lately-revived form of engine.

In the summer of 1832, an engine built by Messrs. Davis & Gartner, of York, Pa., was put on the Baltimore & Ohio road, which at times attained a speed, unloaded, of 30 miles an hour. The engine weighed 3½ tons, and drew, usually, 4 cars, weighing altogether 14 tons, from Baltimore to Ellicott's Mills, a distance of 13 miles, in the schedule-time, one hour.

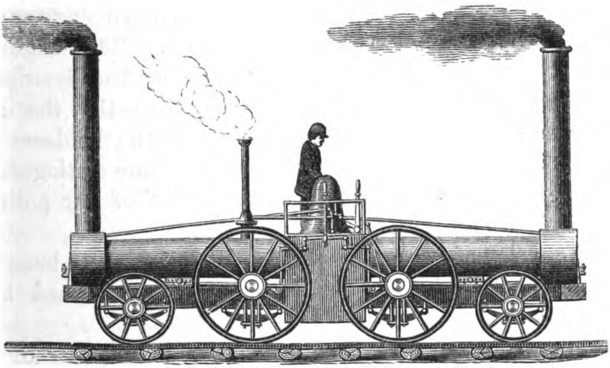


Fig. 62.—The "South Carolina," 1831.

Horatio Allen's engine on the South Carolina Railroad is said to have been the first eight-wheeled engine ever built.

It was at about the time of which we are now writing that the first locomotive was built of what is now distinctively known as the American type—an engine with a "truck" or "bogie" under the forward end of the boiler. This was the "American" No. 1, built at the West Point Foundery, from plans furnished by John B. Jervis, Chief Engineer, for the Mohawk & Hudson Railroad. Ross Winans had already (1831) introduced the passenger-car with swiveling trucks.[1] It was completed in August, 1832, and is said by Mr. Matthew to have been an extremely fast and smooth-running engine. A mile a minute was repeatedly attained, and it is stated by the same authority,[2] that a speed of 80 miles an hour was sometimes made over a single mile. This engine had cylinders 9½ inches diameter, 16 inches stroke of piston, two pairs of driving-wheels, coupled, 5 feet in diameter each; and the truck had four 33-inch wheels. The boiler contained tubes 3 inches in diameter, and its fire-box was 5 feet long and 2 feet 10 inches wide. Robert Stephenson & Co. subsequently built a similar engine, from the plans of Mr. Jervis, and for the same road. It was set at work in 1833. In both engines the driving-wheels were behind the fire-box. This engine is another illustration of the fact—shown by the description already given of other and earlier engines—that the independence of the American mechanic, and the boldness and self-confidence which have to the present time distinguished him, were among the earliest of the fruits of our political independence and freedom.

These American engines were all designed to burn anthracite coal. The English locomotives all burned bituminous coal.

Robert L. Stevens, the President and Engineer of the Camden & Amboy Railroad, and a distinguished son of Colonel John Stevens, of Hoboken, was engaged, at the time of the opening of the Liverpool & Manchester Rail-

---

[1] "History of the First Locomotives in America," Brown.

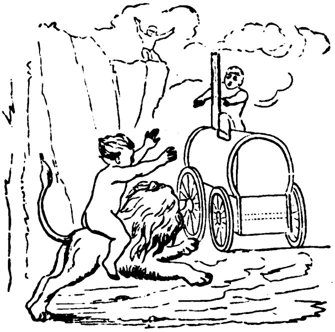
[2] "Ross Winans *vs.* The Eastern Railroad Company—Evidence." Boston, 1854.

The changes which have been outlined produced the now typical American locomotive. It was necessarily given such form that it would work safely and efficiently on rough, ill-ballasted, and often sharply-winding tracks ; and thus it soon became evident that the two pairs of coupled driving-wheels, carrying two-thirds the weight of the whole engine, the forward-truck, and the system of "equalizing" suspension-bars, by which the weight is distributed fairly among all the wheels, whatever the position of the engine, or whatever the irregularity of the track, made it the very best of all known types of locomotive for the railroads of a new country. Experience has shown it equally excellent on the smoothest and best of roads. The "cow-catcher," placed in front to remove obstacles from the track, the bell, and the heavy whistle, are characteristics of the American engine also. The severity of winter-storms compelled the adoption of the "cab," or house, and the use of wood for fuel led to the invention of the "spark-arrester" for that class of engines. The heavy grades on many roads led to the use of the "sand-box," from which sand was sprinkled on the track, to prevent the slipping of the wheels.

In the year 1836, the now standard chilled wheel was introduced for cars and trucks ; the single eccentric, which had been, until then, used on Baldwin engines, was displaced by the double eccentric, with hooks in place of the link ; and, a year later, the iron frame took the place of the previously-used wooden frame on all engines.

The year 1837 introduced a period of great depression in all branches of industry, which continued until the year 1840, or later, and seriously checked all kinds of manufacturing, including the building of locomotives. On the revival of business, numbers of new locomotive-works were started, and in these establishments originated many new types of engine, each of the more successful of which was adapted to some peculiar set of conditions. This variety of type is still seen on nearly all of the principal roads.

The direction of change in the construction of locomotive-engines at the period at which this division of the subject terminates is very well indicated in a letter from Robert Stephenson to Robert L. Stevens, dated 1833, which is now preserved at the Stevens Institute of Technology. He writes: "I am sorry that the feeling in the United States in favour of light railways is so general. In England we are making every succeeding railway stronger and more substantial." He adds: "Small engines are losing ground, and large ones are daily demonstrating that powerful engines are the most economical." He gives a sketch of his latest engine, weighing *nine tons*, and capable, as he states, of "taking 100 tons, gross load, at the rate of 16 or 17 miles an hour on a level." To-day there are engines built weighing 70 tons, and our locomotive-builders have standard sizes guaranteed to draw over 2,000 tons on a good and level track.



CHAPTER V

THE MODERN STEAM-ENGINE

> "Voilà la plus merveilleuse de toutes les Machines; le Mécanisme ressemble à celui des animaux. La chaleur est le principe de son mouvement; il se fait dans ses différens tuyaux une circulation, comme celle du sang dans les veines, ayant des valvules qui s'ouvrent et se ferment à propos; elles se nourrit, s'évacue d'elle même dans les temps réglés, et tire de son travail tout ce qu'il lui faut pour subsister. Cette Machine a pris sa naissance en Angleterre, et toutes les Machines à feu qu'on a construites ailleurs que dans la Grande Brétagne ont été exécutées par des Anglais."—Belidor.

The Second Period of Application—1800–1850 (continued). The Steam-Engine Applied to Ship-Propulsion.

Among the most obviously important and most inconceivably fruitful of all the applications of steam which marked the period we are now studying, is that of the steam-engine to the propulsion of vessels. This direction of application has been that which has, from the earliest period in the history of the steam-engine, attracted the attention of the political economist and the historian, as well as the mechanician, whenever a new improvement, or the revival of an old device, has awakened a faint conception of the possibilities attendant upon the introduction of a machine capable of making so great a force available. The realization of the hopes, the prophecies, and the aspirations of earlier times, in the modern marine steam-engine, may be justly regarded as the greatest of all the triumphs of mechanical engineering. Although, as has already been stated, Ogilby's edition of the "Odyssey" a stanza which reads like a prophecy, and almost awakens a belief that the great poet had a knowledge of steam-vessels in those early times—a thousand years before the Christian era. The prince thus addresses Ulysses:

> "We use nor Helm nor Helms-man. Our tall ships
> Have Souls, and plow with Reason up the deeps;
> All cities, Countries know, and where they list,
> Through billows glide, veiled in obscuring Mist;
> Nor fear they Rocks, nor Dangers on the way."

Pope's translation[1] furnishes the following rendering of Homer's prophecy:

> "So shalt thou instant reach the realm assigned,
> In wondrous ships, self-moved, instinct with mind;
> * * * * *
> Though clouds and darkness veil the encumbered sky,
> Fearless, through darkness and through clouds they fly.
> Though tempests rage, though rolls the swelling main,
> The seas may roll, the tempests swell in vain;
> E'en the stern god that o'er the waves presides,
> Safe as they pass and safe repass the tide,
> With fury burns; while, careless, they convey
> Promiscuous every guest to every bay."

It is stated that the Roman army under Claudius Caudex was taken across to Sicily in boats propelled by paddle-wheels turned by oxen. Vulturius gives pictures of such vessels.

This application of the force of steam was very possibly anticipated 600 years ago by Roger Bacon, the learned Franciscan monk, who, in an age of ignorance and intellectual torpor, wrote:

"I will now mention some wonderful works of art and nature, in which there is nothing of magic, and which magic

---

[1] "Odyssey," Book VIII., p. 175.

could not perform. Instruments may be made by which the largest ships, with only one man guiding them, will be carried with greater velocity than if they were full of sailors," etc., etc.

Darwin's poetical prophecy was published long years before Watt's engine rendered its partial fulfillment a possibility; and thus, for many years before even the first promising effort had been made, the minds of the more intelligent had been prepared to appreciate the invention when it should finally be brought forward.

The earliest attempt to propel a vessel by steam is claimed by Spanish authorities, as has been stated, to have been made by Blasco de Garay, in the harbour of Barcelona, Spain, in 1543. The record, claimed as having been extracted from the Spanish archives at Simancas, states the vessel to have been of 200 tons burden, and to have been moved by paddle-wheels; and it is added that the spectators saw, although not allowed closely to inspect the apparatus, that one part of it was a "vessel of boiling water"; and it is also stated that objection was made to the use of this part of the machine, because of the danger of explosion.

The account seems somewhat apocryphal, and it certainly led to no useful results.

In an anonymous English pamphlet, published in 1651, which is supposed by Stuart to have been written by the Marquis of Worcester, an indefinite reference to what may probably have been the steam-engine is made, and it is there stated to be capable of successful application to propelling boats.

In 1690, Papin proposed to use his piston-engine to drive paddle-wheels to propel vessels; and in 1707 he applied the steam-engine, which he had proposed as a pumping-engine, to driving a model boat on the Fulda at Cassel. In this trial he used the arrangement of which a sketch has been shown, his pumping-engine forcing up water to turn a water-wheel, which, in turn, was made to drive the paddles.

give himself the Trouble to peruse this Essay, will be so candid as to excuse or overlook any Imperfections in the diction or manner of writing, considering the Hand it comes from, if what I have imagined may only appear as plain to others as it has done to me, viz., That the Scheme I now offer is Practicable, and if encouraged will be Useful."

There is no positive evidence that Hulls ever put his scheme to the test of experiment, although tradition does say that he made a model, which he tried with such ill success as to prevent his prosecution of the experiment further; and doggerel rhymes are still extant which were sung by his neighbours in derision of his folly, as they considered it.

A prize was awarded by the French Academy of Sciences, in 1752, for the best essay on the manner of impelling vessels without wind. It was given to Bernouilli, who, in his paper, proposed a set of vanes like those of a windmill—a screw, in fact—one to be placed on each side the vessel, and two more behind. For a vessel of 100 tons, he proposed a shaft 14 feet long and 2 inches in diameter, carrying "eight wheels, for acting on the water, to each of which it" (the shaft) "is perpendicular, and forms an axis for them all; the wheels should be at equal distances from each other. Each wheel consists of 8 arms of iron, each 3 feet long, so that the whole diameter of the wheel is 6 feet. Each of these arms, at the distance of 20 inches from the centre, carries a sheet-iron plane (or paddle) 16 inches square, which is inclined so as to form an angle of 60 degrees, both with the arbour and keel of the vessel, to which the arbour is placed parallel. To sustain this arbour and the wheels, two strong bars of iron, between 2 and 3 inches thick, proceed from the side of the vessel at right angles to it, about 2½ feet below the surface of the water." He proposed similar screw-propellers at the stern, and suggested that they could be driven by animal or by steam-power.

But a more remarkable essay is quoted by Figuier[1]—the paper of l'Abbé Gauthier, published in the "Mémoires de la Société Royale des Sciences et Lettres de Nancy." Bernouilli had expressed the belief that the best steam-engine then known—that of Newcomen—was not superior to some other motors. Gauthier proposed to use that engine in the propulsion of paddle-wheels placed at the side of the vessel. His plan was not brought into use, but his paper embodied a glowing description of the advantages to be secured by its adoption. He states that a galley urged by 26 oars on a side made but 4,320 toises (8,420 meters), or about 5 miles, an hour, and required a crew of 260 men. A steam-engine, doing the same work, would be ready for action at all times, could be applied, when not driving the vessel, to raising the anchor, working the pumps, and to ventilating the ship, while the fire would also serve to cook with. The engine would occupy less space and weight than the men, would require less aliment, and that of a less expensive kind, etc. He would make the boiler safe against explosions by bands of iron; would make the fire-box of iron, with a water-filled ash-pit and base-plate. His injection-water was to come from the sea, and return by a delivery-pipe placed above the water-line. The chains, usually leading from the end of the beam to the pump-rods, were to be carried around wheels on the paddle-shaft, which were to be provided with pawls entering a ratchet, and thus the paddles, having been given several revolutions by the descent of the piston and the unwinding of the chain, were to revolve freely while the return-stroke was made, the chain being hauled down and rewound by the wheel on the shaft, the latter being moved by a weight. The engine was proposed to be of 6 feet stroke, and to make 15 strokes per minute, with a force of 11,000 pounds.

A little later (1760), a Swiss clergyman, J. A. Genevois,

---

[1] "Les Merveilles de la Science."

published in London a paper relating to the improvement of navigation,[1] in which his plan was proposed of compressing springs by steam or other power, and applying their effort while recovering their form to ship-propulsion.

It was at this time that the first attempts were made in the United States to solve this problem, which had begun to be recognized as one of the greatest which had presented itself to the mechanic and the engineer.

WILLIAM HENRY was a prominent citizen of the then little village of Lancaster, Pa., and was noted as an ingenious and successful mechanic.[2] He was still living at the beginning of the present century. Mr. Henry was the first to make the "rag" carpet, and was the inventor of the screw-auger. He was of a Scotch and North-of-Ireland family, his father, John Henry, and his two older brothers, Robert and James, having come to the United States about 1720. Robert settled, finally, in Virginia, and it is said that Patrick Henry, the patriot and orator, was of his family. The others remained in Chester County, Pa., where William was born, in 1729. He learned the trade of a gunsmith, and, driven from his home during the Indian war (1755 to 1760), settled in Lancaster.

In the year 1760 he went to England on business, where his attention was attracted to the invention—then new, and the subject of discussion in every circle—of James Watt. He saw the possibility of its application to navigation and to driving carriages, and, on his return home, commenced the construction of a steam-engine, and finished it in 1763.

Placing it in a boat fitted with paddle-wheels, he made a trial of the new machine on the Conestoga River, near Lancaster, where the craft, by some accident, sank,[3] and

---

[1] "Some New Enquiries tending to the Improvement of Navigation." London, 1760.

[2] *Lancaster Daily Express*, December 10, 1872. This account is collated from various manuscripts and letters in the possession of the author.

[3] Bowen's "Sketches," p. 56.

was lost. He was not discouraged by this failure, but made a second model, adding some improvements. Among the records of the Pennsylvania Philosophical Society is, or was, a design, presented by Henry in 1782, of one of his steamboats. The German traveler Schöpff visited the United States in 1783, and at Mr. Henry's house, at Lancaster, was shown "a machine by Mr. Henry, intended for the propelling of boats, etc.; 'but,' said Mr. Henry, 'I am doubtful whether such a machine would find favour with the public, as every one considers it impracticable against wind and tide;' but that such a Boat *will* come into use and navigate on the waters of the Ohio and Mississippi, he had not the least doubt of, but the time had not yet arrived of its being appreciated and applied."

John Fitch, whose experiments will presently be referred to, was an acquaintance and frequent visitor to the house of Mr. Henry, and may probably have there received the earliest suggestions of the importance of this application of steam. About 1777, when Henry was engaged in making mathematical and philosophical instruments, and the screw-auger, which at that time could only be obtained of him, Robert Fulton, then twelve years old, visited him, to study the paintings of Benjamin West, who had long been a friend and protégé of Henry. He, too, not improbably received there the first suggestion which afterward led him to desert the art to which he at first devoted himself, and which made of the young portrait-painter a successful inventor and engineer. West's acquaintance with Henry had no such result. The young painter was led by his patron and friend to attempt historical pictures,[1] and probably owes his fame greatly to the kindly and discerning mechanic. Says Galt, in his "Memoirs of Sir Benjamin West" (London, 1816): "Towards his old friend, William Henry, of Lancaster City, he always cherished the most

---

[1] Some of West's portraits, including those of Mr. and Mrs. Henry, were lately in the possession of Mr. John Jordan, of Philadelphia.

upon Rumsey's rude arrangements, but which have not done much more than his toward the introduction of "Hydraulic or Jet Propulsion," as it is now called.

In 1787 he obtained a patent from the State of Virginia for steam-navigation. He wrote a treatise "On the Application of Steam," which was printed at Philadelphia, where a Rumsey society was organized for the encouragement of attempts at steam-navigation.

Rumsey died of apoplexy, while explaining some of his schemes before a London society a short time later, December 23, 1793, at the age of fifty years. A boat, then in process of construction from his plans, was afterward tried on the Thames, in 1793, and steamed at the rate of four miles an hour. The State of Kentucky, in 1839, presented his son with a gold medal, commemorative of his father's services "in giving to the world the benefit of the steamboat."

JOHN FITCH was an unfortunate and eccentric, but very ingenious, Connecticut mechanic. After roaming about until forty years of age, he finally settled on the banks of the Delaware, where he built his first steamboat.

In April, 1785, as Fitch himself states, at Neshamony, Bucks County, Pa., he suddenly conceived the idea that a carriage might be driven by steam. After considering the subject a few days, his attention was led to the plan of using steam to propel vessels, and from that time to the day of his death he was a persistent advocate of the introduction of the steamboat. At this time, Fitch says, "I did not know that there was a steam-engine on the earth;" and he was somewhat disappointed when his friend, the Rev. Mr. Irwin, of Neshamony, showed him a sketch of one in "Martin's Philosophy."

Fitch's first model was at once built, and was soon after tried on a small stream near Davisville. The machinery was made of brass, and the boat was impelled by paddle-wheels. A rough model of his steamboat was shown to

Dr. John Ewing, Provost of the University of Pennsylvania, who, August 20, 1785, addressed a commendatory letter to an ex-Member of Congress, William C. Houston, asking him to assist Fitch in securing the aid of the General Government. The latter referred the inventor, by a letter of recommendation, to a delegate from New Jersey, Mr. Lambert Cadwalader. With this, and other letters, Fitch proceeded to New York, where Congress then met, and made his application in proper form. He was unsuccessful, and equally so in attempting to secure aid from the Spanish minister, who desired that the profits should be secured, by a monopoly of the invention, to the King of Spain. Fitch declined further negotiation, determined that, if successful at all, the benefit should accrue to his own countrymen.

In September, 1785, Fitch presented to the American Philosophical Society, at Philadelphia, a model in which he had substituted an endless chain and floats for the paddle-wheels, with drawings and a descriptive account of his scheme. This model is shown in the accompanying figure.

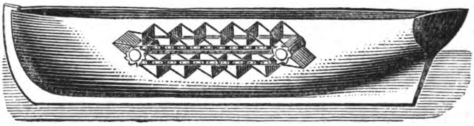


FIG. 67.—Fitch's Model, 1785.

In March, 1786, Fitch was granted a patent by the State of New Jersey, for the exclusive right to the navigation of the waters of the State by steam, for 14 years. A month later, he was in Philadelphia, seeking a similar patent from the State of Pennsylvania. He did not at once succeed, but in a few days he had formed a company, raised $300, and set about finding a place in which to construct his engine. Henry Voight, a Dutch watchmaker, a good mechanic, and a very ingenious man, took an interest in the company, and with him Fitch set about his work with great enthusiasm. After making a little model, having a steam-cylinder but one inch in diameter, they built a model boat and engine, the latter having a diameter of cylinder of three inches. They tried the endless chain, and other methods of propulsion, without success, and finally succeeded with a set of oars worked by the engine. In August, 1776, it was determined by the company to authorize the construction of a larger vessel; but the money was not readily obtained. Meantime, Fitch continued his efforts to secure a patent from the State, and was finally, March 28, 1787, successful. He also obtained a similar grant from the State of Delaware, in February of the same year, and from New York, March 19.

Money was now subscribed more freely, and the work on the boat continued uninterruptedly until May, 1787, when a trial was made, which revealed many defects in the machinery. The cylinder-heads were of wood, and leaked badly; the piston leaked; the condenser was imperfect; the valves were not tight. All these defects were remedied, and a condenser invented by Voight—the "pipe-condenser"—was substituted for that defective detail as previously made.

The steamboat was finally placed in working order, and was found capable, on trial, of making three or four miles an hour. But now the boiler proved to be too small to furnish steam steadily in sufficient quantity to sustain the higher speed. After some delay, and much distress on the part of the sanguine inventor, who feared that he might be at last defeated when on the very verge of success, the necessary changes were finally made, and a trial took place at Philadelphia, in presence of the members of the Convention—then in session at Philadelphia framing the Federal Constitution—August 22, 1787. Many of the distinguished spectators gave letters to Fitch certifying his success. Fitch now went to Virginia, where he succeeded in obtaining a occupied by the "Tombs," the city prison. This little boat was a ship's yawl fitted with a screw, like that adopted later by Woodcroft, and driven by a rudely-made engine.

Fitch, while in the city of Philadelphia at about this time, met Oliver Evans, and discussed with him the probable future of steam-navigation, and proposed to form a company in the West, to promote the introduction of steam on the great rivers of that part of the country. He settled at last in Kentucky, on his land-grant, and there amused himself with a model steamboat, which he placed in a small stream near Bardstown. His death occurred there in July, 1798, and his body still lies in the village cemetery, with only a rough stone to mark the spot.

Both Rumsey and Fitch endeavoured to introduce their methods in Great Britain; and Fitch, while urging the importance and the advantages of his plan, confidently stated his belief that the ocean would soon be crossed by steam-vessels, and that the navigation of the Mississippi would also become exclusively a steam-navigation. His reiterated assertion, "The day will come when some more powerful man will get fame and riches from my invention; but no one will believe that poor John Fitch can do anything worthy of attention," now almost sounds like a prophecy.

During this period, an interest which had never diminished in Great Britain had led to the introduction of experimental steamboats in that country. PATRICK MILLER, of Dalswinton, had commenced experimenting, in 1786–'87, with boats having double or triple hulls, and propelled by paddle-wheels placed between the parts of the compound vessel. James Taylor, a young man who had been engaged as tutor for Mr. Miller's sons, suggested, in 1787, the substitution of steam for the manual power which had been, up to that time, relied upon in their propulsion. Mr. Miller, in 1787, printed a description of his plan of propelling apparatus, and in it stated that he had "reason to believe four daughters were each given a similar annuity. Mr. Miller received no reward, although he is said to have expended over £30,000. The engine of Symmington was condemned by Miller as "the most improper of all steam-engines for giving motion to a vessel." Nothing more was done in Great Britain until early in the succeeding century.

In the United States, several mechanics were now at work besides Fitch. Samuel Morey and Nathan Read were among these. Nicholas Roosevelt was another. It had just been found that American mechanics were able to do the required shop-work. The first experimental steam-engine built in America is stated to have been made in 1773 by Christopher Colles, a lecturer before the American Philosophical Society at Philadelphia. The first steam-cylinder of any considerable size is said[1] to have been made by Sharpe & Curtenius, of New York City.

SAMUEL MOREY was the son of one of the first settlers of Oxford, N. H. He was naturally fond of science and mechanics, and became something of an inventor. He began experimenting with the steamboat in 1790 or earlier, building a small vessel, and fitting it with paddle-wheels driven by a steam-engine of his own design, and constructed by himself.[2] He made a trial-trip one Sunday morning in the summer of 1790, a friend to accompany him, from Oxford, up the Connecticut River, to Fairlee, Vt., a distance of several miles, and returned safely. He then went to New York,[3] and spent the summer of each year until 1793 in experimenting with his boat and modifications of his engine. In 1793 he made a trip to Hartford, returning to New York the next summer. His boat was a "stern-wheeler," and is stated to have been capable of steaming five miles an hour. He next went to Bordentown, N. J., where he built a larger boat, which is said to have been a

---

[1] *Rivington's Gazette*, February 16, 1775.

[2] *Providence Journal*, May 7, 1874.

[3] Westcott.

the feed-water into the boiler,[1] *E* the smoke-pipe, and *F* the steam-pipe leading to the engine. *G* is the "shell" of the boiler, and *H* the fire-box. The crown-sheet, *I I*, has depending from it, in the furnace, a set of water-tubes, *b b*,

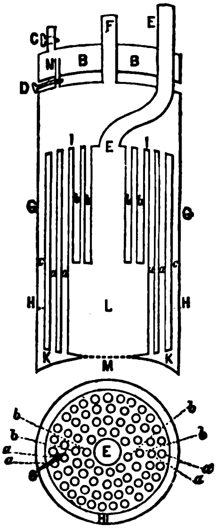


Fig. 73.—Read's Boiler in Section, 1788.

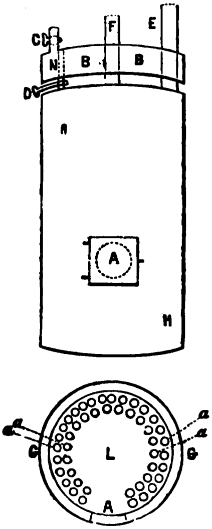


Fig. 74.—Read's Multi-Tubular Boiler, 1788.

closed at their lower ends, and another set, *a a*, which connect the water-space above the furnace with the water-bottom, *K K*. *L* is the furnace, and *M* the draught-space between the boiler and the ash-pit, in which the grates are set.

This boiler was intended to be used in both steamboats and steam-carriages. The first drawings were made in 1788 or 1789, as were those of a peculiar form of steam-engine which also resembled very closely that afterward constructed in Great Britain by Trevithick.[2] He built a

---

[1] This is substantially an arrangement that has recently become common. It has been repatented by later inventors.

[2] "Nathan Read and the Steam-Engine."

and the boat steamed down to Port Glasgow, a distance of about 20 miles, against a strong head-wind, in six hours.

The proprietors of the canal were now urged to adopt the new plan of towing; but, fearing injury to the banks of the canal, they declined to do so. Lord Dundas then laid the matter before the Duke of Bridgewater, who gave Symmington an order for eight boats like the Charlotte Dundas, to be used on his canal. The death of the Duke, however, prevented the contract from being carried into effect, and Symmington again gave up the project in despair. A quarter of a century later, Symmington received from the British Government £100, and, a little later, £50 additional, as an acknowledgment of his services. The Charlotte Dundas was laid up, and we hear nothing more of that vessel.

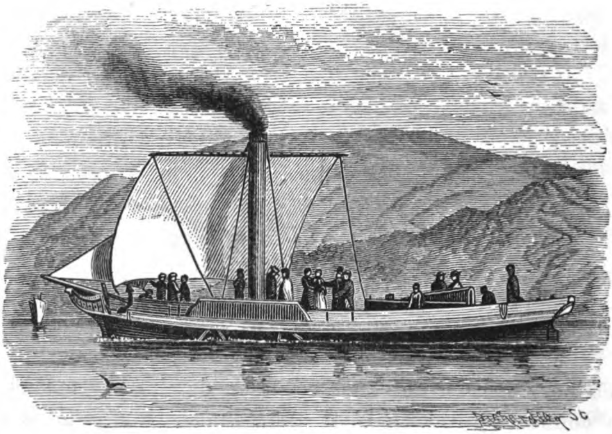


FIG. 76.—The "Comet," 1812.

Among those who saw the Charlotte Dundas, and who appreciated the importance of the success achieved by Symmington, was HENRY BELL, who, 10 years afterward, constructed the Comet (Fig. 76), the first passenger-vessel built in Europe. This vessel was built in 1811, and completed January 18, 1812. The craft was of 30 tons burden, 40 feet in length, and 10½ feet breadth of beam. There were *two* paddle-wheels on each side, driven by engines rated at three horse-power.

Bell had, it is said, been an enthusiastic believer in the advantages to be secured by this application of steam, from about 1786. In 1800, and again in 1803, he applied to the British Admiralty for aid in securing those advantages by experimentally determining the proper form and proportions of machinery and vessel; but was not able to convince the Admiralty of "the practicability and great utility of applying steam to the propelling of vessels against winds and tides, and every obstruction on rivers and seas where there was depth of water." He also wrote to the United States Government, urging his views in a similar strain.

Bell's boat was, when finished, advertised as a passenger-boat, to leave Greenock, where the vessel was built, on Mondays, Wednesdays, and Fridays, for Glasgow, 24 miles distant, returning Tuesdays, Thursdays, and Saturdays. The fare was made "four shillings for the best cabin, and three shillings for the second." It was some months before the vessel became considered a trustworthy means of conveyance. Bell, on the whole, was at first a heavy loser by his venture, although his boat proved itself a safe, stanch vessel.

Bell constructed several other boats in 1815, and with his success steam-navigation in Great Britain was fairly inaugurated. In 1814 there were five steamers, all Scotch, regularly working in British waters; in 1820 there were 34, one-half of which were in England, 14 in Scotland, and the remainder in Ireland. Twenty years later, at the close of the period to which this chapter is especially devoted, there were about 1,325 steam-vessels in that kingdom, of which 1,000 were English and 250 Scotch.

Livingston did not succeed in complying with the terms of the act, but, in 1803, he procured the reënactment of the law in favour of himself and Robert Fulton, who was then experimenting in France, after having, in England, watched the progress of steam-navigation there, and then taken a patent in this country.

Robert Fulton.

ROBERT FULTON was a native of Little Britain, Lancaster County, Pa., born 1765. He commenced experimenting with paddle-wheels when a mere boy, in 1779, visiting an aunt living on the bank of the Conestoga.[1] During his youth he spent much of his time in the workshops of his neighbourhood, and learned the trade of a watchmaker ; but he adopted, finally, the profession of an artist, and exhibited great skill in portrait-painting. While his tastes were

---

[1] *Vide* "Life of Fulton," Reigart.

who was then (1801) Embassador of the United States at the court of France. Together they discussed the project of applying steam to navigation, and determined to attempt the construction of a steamboat on the Seine; and in the early spring of the year 1802, Fulton having attended Mrs. Barlow to Plombières, where she had been sent by her physician, he there made drawings and models, which were sent or described to Livingston. In the following winter Fulton completed a model side-wheel boat.

January 24, 1803, he delivered this model to MM. Molar, Bordel, and Montgolfier, with a descriptive memoir, in which he stated that he had, by experiment, proven that side-wheels were better than the "chaplet" (paddle-floats set on an endless chain).[1] These gentlemen were then building for Fulton and Livingston their first boat, on L'Isle des Cygnes, in the Seine. In planning this boat, Ful-

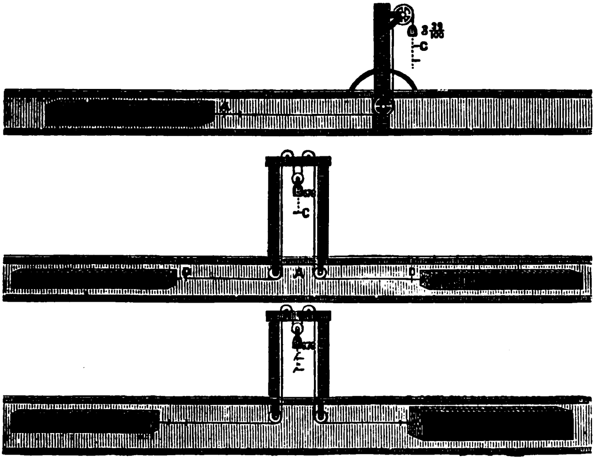


FIG. 77.—Fulton's Experiments.

---

[1] A French inventor, a watchmaker of Trévoux, named Desblancs, had already deposited at the Conservatoire a model fitted with "chaplets."

boat and its results, and procured the passage of an act by the Legislature of the State of New York, extending a monopoly granted him in 1798 for the term of 20 years from April 5, 1803, the date of the new law, and extending the time allowed for proving the practicability of driving a boat four miles an hour by steam to two years from the same date. A later act further extended the time to April, 1807.

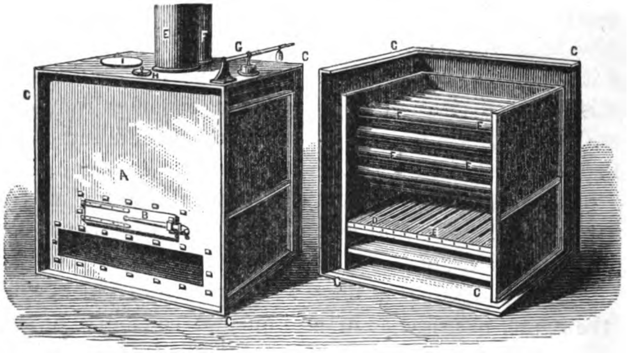


FIG. 79.—Barlow's Water-Tube Boiler, 1798.

In May, 1804, Fulton went to England, giving up all hope of success in France with either his steamboats or his torpedoes. Fulton had already written to Boulton & Watt, ordering an engine to be built from plans which he furnished them; but he had not informed them of the purpose to which it was to be applied. This engine was to have a steam-cylinder 2 feet in diameter and of 4 feet stroke. The engine of the Charlotte Dundas was of very nearly the same size; and this fact, and the visit of Fulton to Symmington in 1801, as described by the latter, have been made the basis of a claim that Fulton was a copyist of the plans of others. The general accordance of the dimensions of his boat on the Seine with those of the "Polacca" of Roosevelt is also made the basis of similar claims by the friends of the latter. It would appear, however, that Symmington's statement is incorrect, as Fulton was in France, experimenting with torpedoes, at the time (July, 1801[1]) when he is accused of having obtained from the English engineer the dimensions and a statement of the performance of his vessel. Yet a fireman employed by Symmington has made an affidavit to the same statement. It is evident, however, from what has preceded, that those inventors and builders who were at that time working with the object of introducing the steamboat were usually well acquainted with what had been done by others, and with what was being done by their contemporaries; and it is undoubtedly the fact that each profited, so far as he was able, by the experience of others.

While in England, however, Fulton was certainly not so entirely absorbed in the torpedo experiments with which he was occupied in the years 1804–'6 as to forget his plans for a steamboat; and he saw the engine ordered by him in 1804 completed in the latter year, and preceded it to New York, sailing from Falmouth in October, 1806, and reaching the United States December 13, 1806.

The engine was soon received, and Fulton immediately contracted for a hull in which to set it up. Meantime, Livingston had also returned to the United States, and the two enthusiasts worked together on a larger steamer than any which had yet been constructed.

In the spring of 1807, the "Clermont" (Fig. 80), as the new boat was christened, was launched from the ship-yard of Charles Brown, on the East River, New York. In August the machinery was on board and in successful operation. The hull of this boat was 133 feet long, 18 wide, and 9 deep. The boat soon made a trip to Albany, running the distance of 150 miles in 32 hours running time, and returning in 30 hours. The sails were not used on either occasion.

---

[1] Woodcroft, p. 64.

This was the first voyage of considerable length ever made by a steam-vessel; and Fulton, though not to be classed with James Watt as an inventor, is entitled to the great honour of having been the first to make steam-navigation an every-day commercial success, and of having thus made the first application of the steam-engine to ship-propulsion, which was not followed by the retirement of the experimenter from the field of his labours before success was permanently insured.

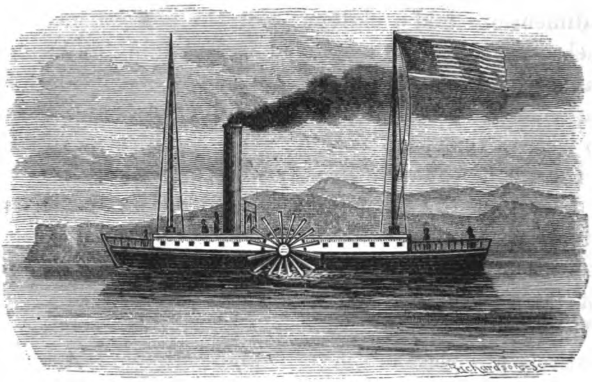


Fig. 80.—The Clermont, 1807.

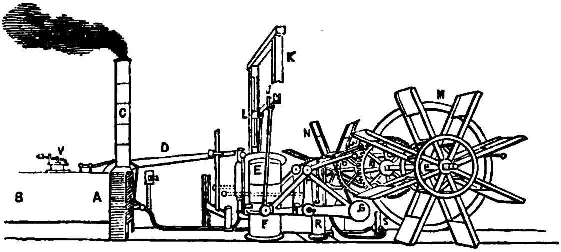


Fig. 81.—Engine of the Clermont, 1808.

The engine of the Clermont (Fig. 81) was of rather pecreditable work, aside from that of the introduction of the steamboat into every-day use, was the experimental determination of the magnitude and the laws of ship-resistance, and the systematic proportioning of vessel and machinery to the work to be done by them.

The success of the Clermont on the trial-trip was such that Fulton soon after advertised the vessel as a regular passenger-boat between New York and Albany.[1]

During the next winter the Clermont was repaired and enlarged, and in the summer of 1808 was again on the route to Albany; and, meantime, two new steamboats—the Raritan and the Car of Neptune—had been built by Fulton. In the year 1811 he built the Paragon. Both of the

---

[1] A newspaper-slip in the scrap-book of the author has the following:

"The traveler of to-day, as he goes on board the great steamboats St. John or Drew, can scarcely imagine the difference between such floating palaces and the wee-bit punts on which our fathers were wafted 60 years ago. We may, however, get some idea of the sort of thing then in use by a perusal of the steamboat announcements of that time, two of which are as follows:

["*Copy of an Advertisement taken from the Albany Gazette, dated September*, 1807.]

"The North River Steamboat will leave Pauler's Hook Ferry [now Jersey City] on Friday, the 4th of September, at 9 in the morning, and arrive at Albany on Saturday, at 9 in the afternoon. Provisions, good berths, and accommodations are provided.

"The charge to each passenger is as follows:

"To Newburg	dols. 3,	time 14 hours.
" Poughkeepsie	" 4,	" 17 "
" Esopus	" 5,	" 20 "
" Hudson	" 5½,	" 30 "
" Albany	" 7,	" 36 "

"For places, apply to William Vandervoort, No. 48 Courtlandt Street, on the corner of Greenwich Street.

"*September* 2, 1807.

["*Extract from the New York Evening Post, dated October* 2, 1807.]

"Mr. Fulton's new-invented *Steamboat*, which is fitted up in a neat style for passengers, and is intended to run from New York to Albany as a Packet, left here this morning with 90 passengers, against a strong headwind. Notwithstanding which, it was judged she moved through the waters at the rate of six miles an hour."

year, with armament and stores on board, the same route was traversed again, the vessel making 5½ miles an hour. The vessel, as thus completed, had a double hull, each about 20 feet longer than the Clermont, and separated by a space 15 feet across. Her engine, having a steam-cylinder 48 inches in diameter and of 5 feet stroke of piston, was furnished with steam by a copper boiler 22 feet long, 12 feet wide, and 8 feet high, and turned a wheel between the two hulls which was 16 feet in diameter, and carried "floats" or "buckets" 14 feet long, and with a dip of 4 feet. The engine was in one of the two hulls, and the boiler in the other. The sides, at the gun-deck, were 4 feet 10 inches thick, and her spar-deck was surrounded by heavy musket-proof bulwarks. The armament consisted of 30 32-pounders, which were intended to discharge red-hot shot. There was one heavy mast for each hull, fitted with large latteen sails. Each end of each hull was fitted with a rudder. Large pumps were carried, which were intended to throw heavy streams of water upon the decks of the enemy, with a view to disabling the foe by wetting his ordnance and ammunition. A submarine gun was to have been carried at each bow, to discharge shot weighing 100 pounds, at a depth of 10 feet below the water-line.

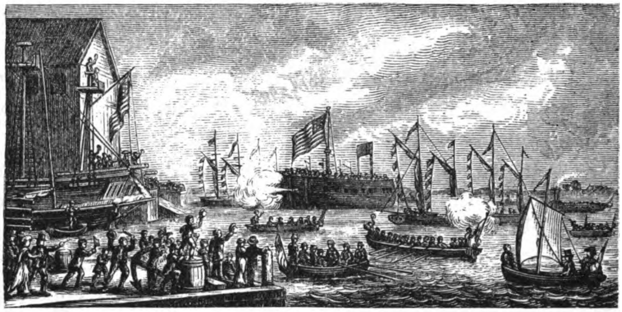


FIG. 82.—Launch of the Fulton the First, 1804.

This was the first application of the steam-engine to naval purposes, and, for the time, it was an exceedingly creditable one. Fulton, however, did not live to see the ship completed. He was engaged in a contest with Livingston, who was then endeavouring to obtain permission from the State of New Jersey to operate a line of steamboats in the waters of the Hudson River and New York Bay, and, while returning from attending a session of the Legislature at Trenton, in January, 1815, was exposed to the weather on the bay at a time when he was ill prepared to withstand it. He was taken ill, and died February 24th of that year. His death was mourned as a national calamity.

From the above brief sketch of this distinguished man and his work, it is seen that, although Robert Fulton is not entitled to distinction as an inventor, he was one of the ablest, most persistent, and most successful of those who have done so much for the world by the introduction of the inventions of others. He was an intelligent engineer and an enterprising business-man, whose skill, acuteness, and energy have given the world the fruits of the inventive genius of all who preceded him, and have thus justly earned for him a fame that can never be lost.

Fulton had some active and enterprising rivals.

Oliver Evans had, in 1801 or 1802, sent one of his engines, of about 150 horse-power, to New Orleans, for the purpose of using it to propel a vessel owned by Messrs. McKeever and Valcourt, which was there awaiting it. The engine was actually set up in the boat, but at a low stage of the river, and no trial could be made until the river should again rise, some months later. Having no funds to carry them through so long a period, Evans's agents were induced to remove the engine again, and to set it up in a saw-mill, where it created great astonishment by its extraordinary performance in sawing lumber.

Livingston and Roosevelt were also engaged in experiments quite as early as Fulton, and perhaps earlier.

A model of this little steamer, built in 1804, is preserved in the lecture-room of the Department of Mechanical Engineering at the Stevens Institute of Technology; and the machinery itself, consisting of the high-pressure "sectional" or "safety" tubular boiler, as it would be called to-day, the high-pressure condensing engine, with rotating valves, and twin screw-propellers, as just described, is given a place of honour in the model-room, or museum, where it contrasts singularly with the mechanism contributed to the collection by manufacturers and inventors of our own time. The hub and blade of a single screw, also used with the same machinery, is likewise to be seen there.

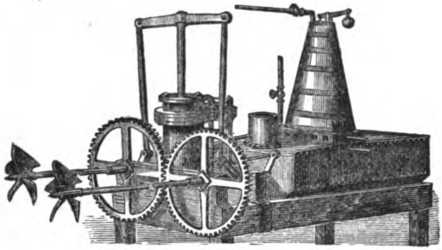


Fig. 84.—Engine, Boiler, and Screw-Propellers used by Stevens, 1804.

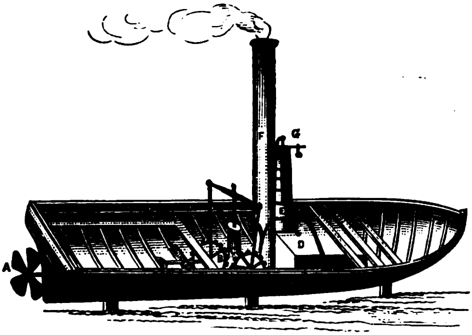


Fig. 85.—Stevens's Screw Steamer, 1804.

navigation of that river would ultimately be effected by steam-vessels.

The changes and improvements which, during the 20 years succeeding the time of Fulton and of John Stevens, gradually led to the adoption of the now recognized type of "American river-boat" and its steam-engine, were principally made by that son of the senior Stevens, who has already been mentioned—Robert L. Stevens—and who became known later as the designer and builder of the first well-planned iron-clad ever constructed, the Stevens Battery. Much of his best work was done during his father's lifetime.

Robert L. Stevens.

He made many extended and most valuable, as well as interesting, experiments on ship-propulsion, expending much time and large sums of money upon them; and many years before they became generally understood, he had arboiler of the steamboat Passaic for it in 1818, and adopted anthracite as a steaming-coal. He used it in a cupola-furnace in the same year, and its use then rapidly became general in the Eastern States.

Stevens continued his work of improving the beam-engine for many years. He designed the now universally-used "skeleton-beam," which is one of the characteristic features of the American engine, and placed the first example of this light and elegant, yet strong, construction on the steamer Hoboken in the year 1822. He built the Trenton, which was then considered an extraordinarily powerful, fast, and handsome vessel, two years afterward, and placed the two boilers on the guards—a custom which is still general on the river steamboats of the Eastern States. In this vessel he also adopted the plan of making the paddle-wheel floats in two parts, placing one above the other, and securing the upper half on the forward and the lower half on the after side of the arm, thus obtaining a smoother action of the wheel, and less loss by oblique pressures.

In 1827 he built the North America (Fig. 88), one of his largest and most successful steamers, a vessel fitted with a pair of engines each 44½ inches in diameter of cylinder and 8 feet stroke of piston, making 24 revolutions per minute, driving the boat 15 to 16 miles an hour. Anticipating difficulty in keeping the long, light, shallow vessel in shape when irregularly laden, and when steaming at the high speed expected to be obtained when her powerful engine was exerting its maximum effort, he adopted the expedient of stiffening the hull by means of a truss of simple form. This proved thoroughly satisfactory, and the "hog-frame," as it has since been inelegantly but universally called, is still one of the peculiar features of every American river-steamer of any considerable size. It was in the North America, also, that he first introduced the artificial blast for forcing the fires, which is still another detail of now usual practice.

New Philadelphia in 1828, and fitted the steam-cylinder with the "double-poppet" valve, which is now universally used on beam-engines. This consists of two disk-valves, connected by the valve-spindle. The disks are of unequal sizes, the smaller passing through the seat of the larger. When seated, the pressure of the steam is, in the steam-valve, taken on the upper side of the larger and the lower side of the smaller disk, thus producing a partial balancing of the valve, and rendering it easy to work the heaviest engine by the hand-gear. The two valve-seats are formed in the top and the bottom, respectively, of the steam-passage leading to the cylinder; and when the valve is raised, the steam enters at the top and the bottom at the same time, and the two currents, uniting, flow together into the steam-cylinder. The same form of valve is used as an exhaust-valve.

At about the same time he built the now standard form of return tubular boilers for moderate pressures. In the figure, *S* is the steam and *W* the water space, and *F* the furnace. The direction of the currents of smoke and gas are shown by the arrows.

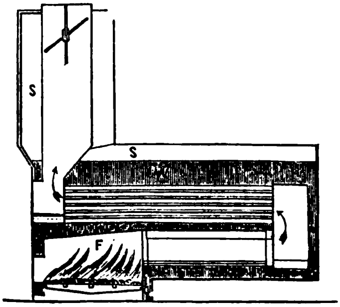


FIG. 89.—Stevens's Return Tubular Boiler, 1832.

Some years later (1840), Stevens commenced using steam-packed pistons on the Trenton, in which steam was admitted by self-adjusting valves behind the metallic packing-rings, setting them out more effectively than did the steel springs then (and still) usually employed.

His pistons, thus fitted, worked well for many years. A set of the small brass check-valves used in a piston of this kind, built by Stevens, and preserved in the cabinets of the Stevens Institute of Technology, are good evidence of the ingenuity and excellent workmanship which distinguished the machinery constructed under the direction of this great engineer.

The now familiar "Stevens cut-off," a peculiar device for securing the expansion of steam in the steam-cylinder, was the invention (1841) of Robert L. Stevens and a nephew, who inherited the same constructive talent which distinguished the first of these great men—Mr. Francis B. Stevens. In this form of valve-gear, the steam and exhaust valves are independently worked by separate eccentrics, the latter being set in the usual manner, opening and closing the exhaust-passages just before the crank passes its centre. The steam-eccentric is so placed that the steam-valve is opened as usual, but closed when but about one-half the stroke has been made. This result is accomplished by giving the eccentric a greater throw than is required by the motion of the valve, and permitting it to move through a portion of its path without moving the valve. Thus, in Fig. 90, if $A B$ be the direction of motion of the eccentric-rod, the valve would ordinarily open the steam-port when the eccentric assumes the position $O C$, closing when the eccentric has passed around to $O D$. With the Stevens valve-gear, the valve is opened when the eccentric reaches $O E$, and closes when it arrives at $O F$. The steam-valve of the opposite end of the cylinder is open while the eccentric is moving from $O M$ to $O K$. Between K and E, and

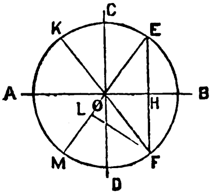


FIG. 90.—Stevens's Valve-Motion.

was 6¾ inches—2¼ inches thicker than that of the first French and British iron-clads—and the machinery was designed by Mr. Stevens to be of 8,624 indicated horse-power, driving twin-screws, and propelling the vessel 20 miles or more an hour. As with the preceding design, the progress of construction was intermittent and very slow. Government advanced funds, and then refused to continue the work; successive administrations alternately encouraged and discouraged the engineer; and he finally, cutting loose entirely from all official connections, went on with the work at his own expense.

The remarkable genius of the elder Stevens was well reflected in the character of his son, and is in no way better exemplified than by the accuracy with which, in this great ship, those forms and proportions, both of hull and machinery, were adopted which are now, twenty-five years later, recognized as most correct under similar conditions. The lines of the vessel are beautifully fair and fine, and are what J. Scott Russell has called "wave-lines," or trochoidal lines, such as Rankine has shown to be the best possible for easy propulsion. The proportion of length to midship dimensions is such as to secure the speed proposed with a minimum resistance, and to accord closely with the proportions arrived at and adopted by common consent in present transoceanic navigation by the best—not to say radical—builders.

The death of Robert L. Stevens occurred in April, 1856, when this larger vessel had advanced so far toward completion that the hull and machinery were practically finished, and it only remained to add the armour-plating, and to decide upon the form of fighting-house and upon the number and size of guns. The construction of the vessel, which had proceeded slowly and intermittently during the years of peace, as successive administrations had considered it necessary to continue the payment of appropriations, or had stopped temporarily in the absence of any apparent immewas succeeded, in 1827–'28, by a larger vessel, the Rushlight, for which the engine was built by James P. Allaire, at New York, while the boat was built at Newport. The boilers of both vessels had tubes of cast-iron. The smaller of these boats was of 80 tons burden; it steamed from Newport to Providence, 30 miles, in 3½ hours, and to New York, a distance of 175 miles, in 25 hours, using 1¾ cord of wood.[1] Thurston and Babcock subsequently removed to Providence, where the latter soon died. Thurston continued to build steam-engines at this place until nearly a half-century later, dying in 1874.[2] The establishment founded by him, after various changes, became the Providence Steam-Engine Works.

James P. Allaire, of New York, the West Point Iron Foundery, at West Point, on the Hudson River, and Daniel Copeland and his son, Charles W. Copeland, on the Connecticut River, were also early builders of engines for steam-vessels. Daniel Copeland was probably the first (1850) to adopt a slide-valve working with a lap to secure the expansion of steam. His steamboats were then usually stern-wheel vessels, and were built to ply on several routes on the Connecticut River and Long Island Sound. The son, Charles W. Copeland, went to West Point, and while there designed some heavy marine steam-machinery, and subsequently designed several steam vessels-of-war for the United States Navy. He was the earliest designer of iron steamers in the United States, building the Siamese in 1838. This steamer was intended for use on Lake Pontchartrain and the canal to New Orleans. It had two hulls, was 110 feet long, and drew but 22 inches of water, loaded. The two horizontal non-condensing engines turned a single paddle-wheel placed between the two hulls, driving the boat 10 miles an hour. The hull was constructed of plates

---

[1] *American Journal of Science*, March, 1827; *London Mechanics' Magazine*, June 16, 1827.

[2] "New Universal Cyclopædia," vol. iv., 1878.

of iron 10 feet long, formed on blocks after having been heated in a furnace constructed especially for the purpose. The frames were of T-iron, which was probably here used for the first time. The same engineer, associated with Samuel Hart, a well-known naval constructor, built, in 1841, for the United States Navy, the iron steamer Michigan, a war-vessel intended for service on the great northern lakes. This vessel is still in service, and in good order. The hull is 162½ feet in length, 27 feet in breadth, and 12½ feet in depth, measuring 500 tons. The frames were made of T-iron, stiffened by reverse bars of L-iron. The keel-plate was ⅝ inch thick, the bottom plates ⅜, and the sides $\frac{3}{16}$ inch. The deck-beams were of iron, and the vessel, as a whole, was a good specimen of iron-ship building.

During the period from 1830 to 1840, a considerable number of the now standard details of steam-engine and steamboat construction were devised or introduced by Copeland. He was probably the first to use (on the Fulton, 1840) an independent engine to drive the blowing-fans where an artificial draught was required. He made a practice of fitting his steamers with a "bilge-injection," by means of which the vessel could be freed of water, through the condenser and air-pump, when leaking seriously; the condensing-water is, in such a case, taken from inside the vessel, instead of from the sea. This is probably an American device. It was in use in the United States previously to 1835, as was the use of anthracite coal on steamers, which was continued by Copeland in manufacturing and in air-furnaces, as well as on steamboats. He also modified the form of Stevens's double-poppet valve, giving it such shape that it was comparatively easy to grind it tight and to keep it in order.

In 1825, James P. Allaire, of New York, built compound engines for the Henry Eckford, and subsequently constructed similar engines for several other steamers, one of which, the Sun, made the trip from New York to Albany in 12 hours 18 minutes. He used steam at 100 pounds sea-boat. The enterprise was, however, pecuniarily a failure, and the vessel was sold to the Brazilian Government after the removal of the engine. In 1825 the steamer Enterprise made a voyage to India, sailing and steaming as the weather and the supply of fuel permitted. The voyage occupied 47 days.

Notwithstanding these successful passages across the ocean, and the complete success of the steamboat in rivers and harbours, it was asserted, as late as 1838, by many who were regarded as authority, that the passage of the ocean by steamers was quite impracticable, unless possibly they could steam from the coasts of Europe to Newfoundland or to the Azores, and, replenishing their coal-bunkers, resume their voyages to the larger American ports. The voyage was, however, actually accomplished by two steamers in the year just mentioned. These were the Sirius, a ship of 700 tons and of 250 horse-power, and the Great Western, of 1,340 tons and 450 horse-power. The latter was built for this service, and was a large ship for that time, measuring 236 feet in length. Her wheels were 28 feet in diameter, and 10 feet in breadth of face. The Sirius sailed from Cork April 4, 1838, and the Great Western from Bristol April 8th, both arriving at New York on the same day—April 23d—the Sirius in the morning, and the Great Western in the afternoon.

The Great Western carried out of Bristol 660 tons of coal. Seven passengers chose to take advantage of the opportunity, and made the voyage in one-half the time usually occupied by the sailing-packets of that day. Throughout the voyage the wind and sea were nearly ahead, and the two vessels pursued the same course, under very similar conditions. Arriving at New York, they were received with the greatest possible enthusiasm. They were saluted by the forts and the men-of-war in the harbour; the merchant-vessels dipped their flags, and the citizens assembled on the Battery, and, coming to meet them in boats of all kinds and sizes, cheered heartily. The newspapers of the time were filled with the story of the voyage and with descriptions of the steamers themselves and of their machinery.

A few days later the two steamers started on their return to Great Britain, the Sirius reaching Falmouth safely in 18 days, and the Great Western making the voyage to Bristol in 15 days, the latter meeting with head-winds and working, during a part of the time, against a heavy gale and in a high sea, at the rate of but two knots an hour. The Sirius was thought too small for this long and boisterous route, and was withdrawn and replaced on the line between London and Cork, where the ship had previously been employed. The Great Western continued several years in the transatlantic trade.

Thus these two voyages inaugurated a transoceanic steam-service, which has steadily grown in extent and in importance. The use of steam-power for this work of extended ocean-transportation has never since been interrupted. During the succeeding six years the Great Western made 70 passages across the Atlantic, occupying on the voyages to the westward an average of 15½ days, and eastward 13½. The quickest passage to New York was made in May, 1843, in 12 days and 18 hours, and the fastest steaming was logged 12 months earlier, when the voyage from New York was made in 12 days and 7 hours.

Meantime, several other steamers were built and placed in the transatlantic trade. Among these were the Royal William, the British Queen, the President, the Liverpool, and the Great Britain. The latter, the finest of the fleet, was launched in 1843. This steamer was 300 feet long, 50 feet beam, and of 1,000 horse-power. The hull was of iron, and the whole ship was an example of the very best work of that time. After several voyages, this vessel went ashore on the coast of Ireland, and there remained several weeks, but was finally got off, without having suffered serious injury—a remarkable illustration of the stanchness of an iron hull when well built and of good material. The vessel was repaired, and many years afterward was still afloat, and engaged in the transportation of passengers and merchandise to Australia.

The "Cunard Line" of transatlantic steamers was established in the year 1840. The first of the line—the Britannia—sailed from Liverpool for New York, July 4th of that year, and was followed, on regular sailing-days, by the other three of the four ships with which the company commenced business. These four vessels had an aggregate tonnage of 4,600 tons, and their speed was less than eight knots. To-day, the tonnage of a single vessel of the fleet exceeds that of the four; the total tonnage has risen to many times that above given. There are 50 steamers in the line, aggregating nearly 50,000 horse-power. The speed of the steamships of the present time is double that of the vessels of that date, and passages are not infrequently made in eight days.

The form of steam-engine in most general use at this time, on transatlantic steamers, was that known as the "side-lever engine." It was first given the standard form by Messrs. Maudsley & Co., of London, about 1835, and was built by them for steamers supplied to the British Government for general mail service.

The steam-vessels of the time are well represented in the accompanying engraving (Fig. 91) of the steamship Atlantic—a vessel which was shortly afterward (1851) built as the pioneer steamer of the American "Collins Line." This steamship was one of several which formed the earliest of American steamship-lines, and is one of the finest examples of the type of paddle-steamers which was finally superseded by the later screw-fleets. The "Collins Line" existed but a very few years, and its failure was probably determined as much by the evident and inevitable success of screw-propulsion as by the difficulty of securing ample capital, complete organization, and efficient general manage-of F. P. Smith, and this "Ship-Propeller Company" built an experimental craft called the Archimedes, and its trial-trip was made October 14th of the same year. The speed attained was 9.64 miles an hour. The result was in every respect satisfactory, and the vessel, subsequently, made many voyages from port to port, and finally circumnavigated the island of Great Britain. The proprietors of the ship were not pecuniarily successful in their venture, however, and the sale of the vessel left the company a heavy loser. The Archimedes was 125 feet long, of 21 feet 10 inches beam, and 10 feet draught, registering 232 tons. The engines were rated at 80 horse-power. Smith's earlier experiments (1837) were made with a little craft of 6 tons burden, driven by an engine having a steam-cylinder 6 inches in diameter and 15 inches stroke of piston. The funds needed were furnished by a London banker—Mr. Wright.

Bennett Woodcroft had also used the screw experimentally as early as 1832, on the Irwell, near Manchester, England, in a boat of 55 tons burden. Twin-screws were used, right and left handed respectively; they were each two feet in diameter, and were given an expanding pitch. The boat attained a speed of four miles an hour.

Experiments made subsequently (1843) with this form of screw, and in competition with the "true" screw of Smith, brought out very distinctly the superiority of the former, and gave some knowledge of the proper proportions for maximum efficiency. In later examples of the Woodcroft screw, the blades were made detachable and adjustable—a plan which is still a usual one, and which has proved to be, in some respects, very convenient.

When Ericsson reached the United States, he was almost immediately given an opportunity to build the Princeton—a large screw-steamer—and at about the same time the English and French Governments also had screw-steamers built from his plans, or from those of his agent in England, the Count de Rosen. In these latter ships—the Amphion and the Pomona—the first horizontal direct-acting engines ever built were used, and they were fitted with double-acting air-pumps, having canvas valves and other novel features. The great advantages exhibited by these vessels over the paddle-steamers of the time did for screw-propulsion what Stephenson's locomotive—the Rocket—did for railroad locomotion ten years earlier.

Congress, in 1839, had authorized the construction of three war-vessels, and the Secretary of the Navy ordered that two be at once built in the succeeding year. Of these, one was the Princeton, the screw-steamer of which the machinery was designed by Ericsson. The length of this vessel was 164 feet, beam 30½ feet, and depth 21½ feet. The ship drew from 16½ to 18 feet of water, displacing at those draughts 950 and 1,050 tons. The hull had a broad, flat floor, with sharp entrance and fine run, and the lines were considered at that time remarkably fine.

The screw was of gun-bronze, six-bladed, and was 14 feet in diameter and of 35 feet pitch; i. e., were there no slip, the screw working as if in a solid nut, the ship would have been driven forward 35 feet at each revolution.

The engines were two in number, and very peculiar in form; the cylinder was, in fact, a *semi*-cylinder, and the place of the piston-rod, as usually built, was taken by a vibrating shaft, or "rock-shaft," which carried a piston of rectangular form, and which vibrated like a door on its hinges as the steam was alternately let into and exhausted from each side of it. The great rock-shaft carried, at the outer end, an arm from which a connecting-rod led to the crank, thus forming a "direct-acting engine."

The draught in the boilers was urged by blowers. Ericsson had adopted this method of securing an artificial draught ten years before, in one of his earlier vessels, the Corsair. The Princeton carried a XII-inch wrought-iron gun. This gun exploded after a few trials, with terribly disastrous results, causing the death of several distinguished men, including members of the President's cabinet.

The Princeton proved very successful as a screw-steamer, attaining a speed of 13 knots, and was then considered very remarkably fast. Captain Stockton, who commanded the vessel, was most enthusiastic in praise of her.

Immediately there began a revolution in both civil and naval ship-building, which progressed with great rapidity. The Princeton was the first of the screw-propelled navy which has now entirely displaced the older type of steam-vessel. The introduction of the screw now took place with great rapidity. Six steamers were fitted with Ericsson's screw in 1841, 9 in 1842, and nearly 30 in the year 1843.

In Great Britain, France, Germany, and other European countries, the revolution was also finally effected, and was equally complete. Nearly all sea-going vessels built toward the close of the period here considered were screw-steamers, fitted with direct-acting, quick-working engines. It was, however, many years before the experience of engineers in the designing and in the construction and management of this new machinery enabled them to properly proportion it for the various kinds of service to which they were called upon to adapt it. Among other modifications of earlier practice introduced by Ericsson was the surface-condenser with a circulating pump driven by a small independent engine.

The screw was found to possess many advantages over the paddle-wheel as an instrument for ship-propulsion. The cost of machinery was greatly reduced by its use; the expense of maintenance in working order was, however, somewhat increased. The latter disadvantage was, nevertheless, much more than compensated by an immense increase in the economy of ship-propulsion, which marked the substitution of the new instrument and its impelling machinery.

When a ship is propelled by paddles, the motion of the vessel creates, in consequence of the friction of the fluid against the sides and bottom, a current of water which flows in the direction in which the ship is moving, and forms a current following the ship for a time, and finally losing all motion by contact with the surrounding mass of water. All the power expended in the production of this great stream is, in the case of the paddle-steamer, entirely lost. In screw-steamers, however, the propelling instrument works in this following current, and the tendency of its action is to bring the agitated fluid to rest, taking up and thus restoring, usefully, a large part of that energy which would otherwise have been lost. The screw is also completely covered by the water, and acts with comparative efficiency in consequence of its submersion. The rotation of the screw is comparatively rapid and smooth, also, and this permits the use of small, light, fast-running engines. The latter condition leads to economy of weight and space, and consequently saves not only the cost of transportation of the excess of weight of the larger kind of engine, but, leaving so much more room for paying cargo, the gain is found to be a double one. Still further, the quick-running engine is, other things being equal, the most economical of steam; and thus some expense is saved not only in the purchase of fuel, but in its transportation, and some still additional gain is derived from the increased amount of paying cargo which the vessel is thus enabled to carry. The change here described was thus found to be productive of enormous direct gain. Indirectly, also, some advantage was derived from the greater convenience of a deck clear from machinery and the great paddle-shaft, in the better storage of the lading, the greater facility with which the masts and sails could be fitted and used; and directly, again, in clear sides unencumbered by great paddle-boxes which impeded the vessel by catching both sea and wind.

The screw was, for some years, generally regarded as simply auxiliary in large vessels, assisting the sails. Ultifor the Hudson River at the end of the first quarter of the nineteenth century are said to have been very successful vessels. Carrying 75 to 100 pounds of steam in their boilers, the Swiftsure and her contemporaries were by that circumstance well fitted to make that form of engine economically a success. This form of engine was built occasionally during the succeeding quarter of a century, but only became a recognized standard type after the close of the epoch to the history of which this chapter is devoted. That latest and greatest advance in the direction of increased efficiency in the marine steam-engine was, however, commenced very soon after Watt's death, and its completion was the work of nearly a half-century.

CHAPTER VI.

THE STEAM-ENGINE OF TO-DAY.

. . . "AND, last of all, with inimitable power, and 'with whirlwind sound,' comes the potent agency of steam. In comparison with the past, what centuries of improvement has this single agent comprised in the short compass of fifty years! Everywhere practicable, everywhere efficient, it has an arm a thousand times stronger than that of Hercules, and to which human ingenuity is capable of fitting a thousand times as many hands as belonged to Briareus. Steam is found in triumphant operation on the seas; and, under the influence of its strong propulsion, the gallant ship—

'Against the wind, against the tide,
Still steadies with an upright keel.'

It is on the rivers, and the boatman may repose on his oars; it is on highways, and exerts itself along the courses of land-conveyance; it is at the bottom of mines, a thousand feet below the earth's surface; it is in the mills, and in the workshops of the trades. It rows, it pumps, it excavates, it carries, it draws, it lifts, it hammers, it spins, it weaves, it prints. It seems to say to men, at least to the class of artisans: 'Leave off your manual labour; give over your bodily toil; bestow but your skill and reason to the directing of my power, and I will bear the toil, with no muscle to grow weary, no nerve to relax, no breast to feel faintness!' What further improvement may still be made in the use of this astonishing power it is impossible to know, and it were vain to conjecture. What we do know is, that it has most essentially altered the face of affairs, and that no visible limit yet appears beyond which its progress is seen to be impossible."—DANIEL WEBSTER.

THE PERIOD OF REFINEMENT—1850 TO DATE.

BY the middle of the present century, as we have now seen, the steam-engine had been applied, and successfully, to every great purpose for which it was fitted. Its first application was to the elevation of water; it next was applied to the driving of mills and machinery; and it finally became the great propelling power in transportation by land and by sea.

At the beginning of the period to which we are now come, these applications of steam-power had become familiar both to the engineer and to the public. The forms of engine adapted to each purpose had been determined, and had become usually standard. Every type of the modern steam-engine had assumed, more or less closely, the form and proportions which are now familiar; and the most intelligent designers and builders had been taught—by experience rather than by theory, for the theory of the steam-engine had then been but little investigated, and the principles and laws of thermodynamics had not been traced in their application to this engine—the principles of construction essential to successful practice, and were gradually learning the relative standing of the many forms of steam-engine, from among which have been preserved a few specially fitted for certain specific methods of utilization of power.

During the years succeeding the date 1850, therefore, the growth of the steam-engine had been, not a change of standard type, or the addition of new parts, but a gradual improvement in forms, proportions, and arrangements of details; and this period has been marked by the dying out of the forms of engine least fitted to succeed in competition with others, and the retention of the latter has been an example of "the survival of the fittest." This has therefore been a Period of Refinement.

During this period invention has been confined to details; it has produced new forms of parts, new arrangements of details; it has devised an immense variety of valves, valve-motions, regulating apparatus, and a still greater variety of steam-boilers and of attachments, essential and non-essential, to both engines and boilers. The great majority of these peculiar devices have been of no value, and very many of the best of them have been found to have about equal value. All the well-known and successful forms of engine, when equally well designed and constructed and equally well managed, are of very nearly equal efficiency; all of the best-known types of steam-boiler, where given equal proportions of grate to heating-surface and equally well designed, with a view to securing a good draught and a good circulation of water, have been found to give very nearly equally good results; and it has become evident that a good knowledge of principles and of practice, on the part of the designer, the constructor, and the manager of the boiler, is essential in the endeavour to achieve economical success; that good engineering is demanded, rather than great ingenuity. The inventor has been superseded here by the engineer.

The knowledge acquired in the time of Watt, of the essential principles of steam-engine construction, has since become generally familiar to the better class of engineers. It has led to the selection of simple, strong, and durable forms of engine and boiler, to the introduction of various kinds of valves and of valve-gearing, capable of adjustment to any desired range of expansive working, and to the attachment of efficient forms of governor to regulate the speed of the engine, by determining automatically the point of cut-off which will, at any instant, best adjust the energy exerted by the expanding steam to the demand made by the work to be done.

The value of high pressures and considerable expansion was recognized as long ago as in the early part of the present century, and Watt, by combining skillfully the several principal parts of the steam-engine, gave it very nearly the shape which it has to-day. The compound engine, even, as has been seen, was invented by contemporaries of Watt, and the only important modifications since his time have occurred in details. The introduction of the "drop cut-off," the attachment of the governor to the expansion-apparatus in such a manner as to determine the degree of expansion, the improvement of proportions, the introduction of higher steam and greater expansion, the improvement of the marine engine by the adoption of surface-condensation, in addition to these other changes, and the introduction of the double-cylinder engine, after the elevation of steam-pressure and increase of expansion had gone so far as to justify its use, are the changes, therefore, which have taken place during this last quarter-century. It began then to be generally understood that expansion of steam produced economy, and mechanics and inventors vied with each other in the effort to obtain a form of valve-gear which should secure the immense saving which an abstract consideration of the expansion of gases according to Marriotte's law would seem to promise. The counteracting phenomena of internal condensation and reëvaporation, of the losses of heat externally and internally, and of the effect of defective vacuum, defective distribution of steam, and of back-pressure, were either unobserved or were entirely overlooked.

It was many years, therefore, before engine-builders became convinced that no improvement upon existing forms of expansion-gear could secure even an approximation to theoretical efficiency.

The fact thus learned, that the benefit of expansive working has a limit which is very soon reached in ordinary practice, was not then, and has only recently become, generally known among our steam-engine builders, and for several years, during the period upon which we now enter, there continued the keenest competition between makers of rival forms of expansion-gear, and inventors were continually endeavouring to produce something which should far excel any previously-existing device.

In Europe, as in the United States, efforts to "improve" standard designs have usually resulted in injuring their efficiency, and in simply adding to the first cost and running expense of the engines, without securing a marked increase in economy in the consumption of steam.

SECTION I.—STATIONARY ENGINES.

"STATIONARY ENGINES" had been applied to the operation of mill-machinery, as has been seen, by Watt and by Murdoch, his assistant and pupil; and Watt's competitors, in Great Britain and abroad, had made considerable progress before the death of the great engineer, in its adaptation to its work. In the United States, Oliver Evans had introduced the non-condensing high-pressure stationary engine, which was the progenitor of the standard engine of that type which is now used far more generally than any other form. These engines were at first rude in design, badly proportioned, rough and inaccurate as to workmanship, and uneconomical in their consumption of fuel. Gradually, however, when made by reputable builders, they assumed neat and strong shapes, good proportions, and were well made and of excellent materials, doing their work with comparatively little waste of heat or of fuel.

One of the neatest and best modern designs of stationary engine for small powers is seen in Fig. 93, which represents a "vertical direct-acting engine," with base-plate—a form which is a favourite with many engineers.

The engine shown in the engraving consists of two principal parts, the cylinder and the frame, which is a tapering column having openings in the sides, to allow free access to all the working parts within. The slides and pillow-blocks are cast with the column, so that they cannot become loose or out of line; the rubbing surfaces are large and easily lubricated. Owing to the vertical position, there is no tendency to side wear of cylinder or piston. The packing-rings are self-adjusting, and work free but tight. The crank is counterbalanced; the crank-pin, cross-head pin, piston-rod, valve-stem, etc., are made of steel; all the bearing surfaces are made extra large, and are accurately fitted; and the best quality of Babbitt-metal only used for the journal-bearings.

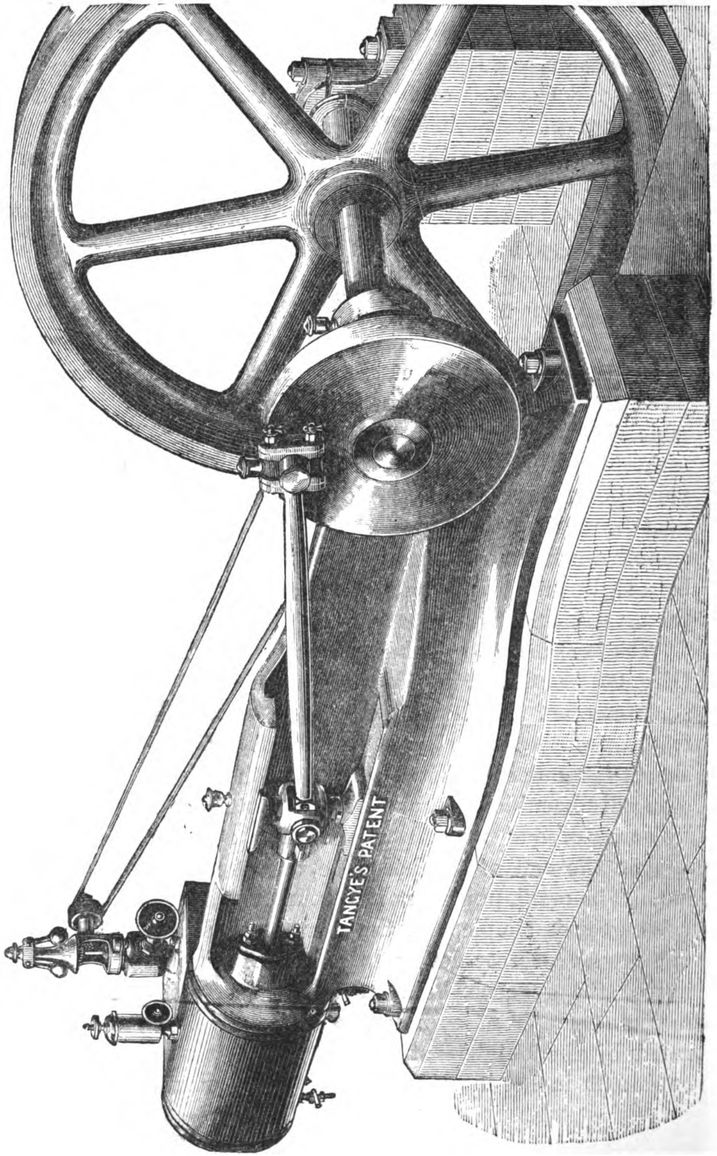


Fig. 95.—Horizontal Stationary Steam-Engine.

225 to 250 horse-power. In this example, all parts are made to exact size by gauges standardized to Whitworth's sizes.

In American engines (as is seen in Fig. 96), usually, two supports are placed—the one under the latter bearing, and the other under the cylinder—to take the weight of the engine; and through them it is secured to the foundation. As in the vertical engine already described, a valve is sometimes used, consisting of two pistons connected by a

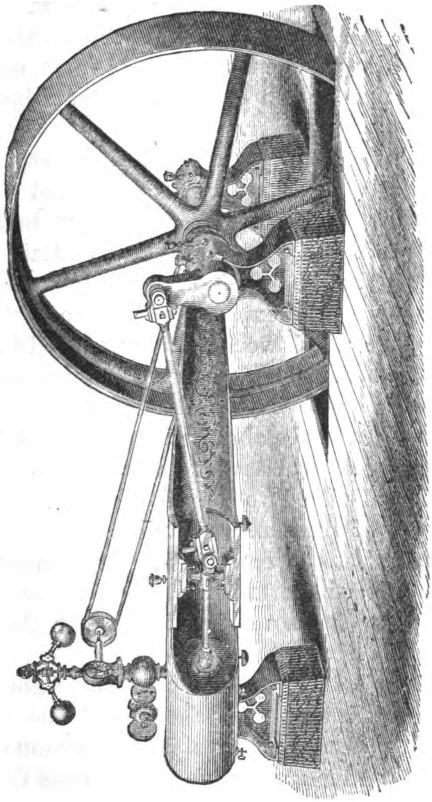


Fig. 96.—Horizontal Stationary Steam-Engine.

ally obtained with coupled engines at ordinary speeds. The ports and valve-movements, the weight of the reciprocating parts, and the size and weight of the fly-wheels, should be calculated expressly for the speeds chosen.

The economy of the engine here described is unexcelled by the best of the more familiar "drop cut-off" engines.

An engine reported upon by a committee of the American Institute, of which Dr. Barnard was chairman, was non-condensing, 16 inches in diameter of cylinder, 30 inches stroke, making 125 revolutions per minute, and developed over 125 horse-power with 75 pounds of steam in the boiler, using 25¾ pounds of steam per indicated horse-power, and 2.87 pounds of coal—an extraordinarily good performance for an engine of such small power.

The governor used on this engine is known as the Porter governor. It is given great power and delicacy by weighting it down, and thus obtaining a high velocity of rotation, and by suspending the balls from forked arms, which are given each two bearing-pins separated laterally so far as to permit considerable force to be exerted in changing speeds without cramping those bearings sufficiently to seriously impair the sensitiveness of the governor. This engine as a whole may be regarded as a good representative of the high-speed engine of to-day.

Since this change in the direction of high speeds has already gone so far that the "drop cut-off" is sometimes inapplicable, in consequence of the fact that the piston would, were such a valve-gear adopted, reach the end of its stroke before the detached valve could reach its seat; and since this progress is only limited by our attainments in mechanical skill and accuracy, it seems probable that the "positive-motion expansion-gear" type of engine will ultimately supersede the now standard "drop cut-off engine."

The best known and most generally used class of stationary engines at the present time is, however, that which arranged, in stationary engines, with a view simply to securing efficiency, and the design is determined by circumstances. It was formerly usual to adopt the condensing engine in mills, and wherever a stationary engine was required. In Europe generally, and to some extent in the United States, where a supply of condensing water is obtainable, condensing engines and moderate steam-pressures are still employed. But this type of engine is gradually becoming superseded by the high-pressure condensing engine, with considerable expansion, and with an expansion-gear in which the point of cut-off is determined by the governor.

The best-known engine of this class is the Corliss engine, which is very extensively used in the United States, and which has been copied very generally by European builders. Fig. 97 represents the Corliss engine. The horizontal steam-cylinder is bolted firmly to the end of the frame, which is so formed as to transmit the strain to the main journal with the greatest directness. The frame carries the guides for the cross-head, which are both in the same vertical plane. The valves are four in number, a steam and an exhaust valve being placed at each end of the steam-cylinder. Short steam-passages are thus secured, and

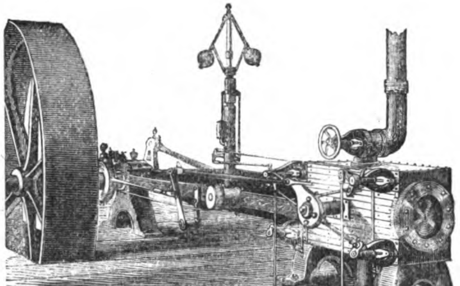


FIG. 97.—Corliss Engine.

extent, when the engine begins to run above the proper speed. When the catch is thrown out, the valve is closed by a weight or a strong spring. To prevent jar when the motion of the valve is checked, a "dash-pot" is used, invented originally by F. E. Sickels. This is a vessel having a nicely-fitted piston, which is received by a "cushion" of water or air when the piston suddenly enters the cylinder at the end of the valve-movement. In the original water dash-pot of Sickels, the cylinder is vertical, and the plunger or piston descends upon a small body of water confined in the base of the dash-pot. Corliss's air dash-pot is now often set horizontally.

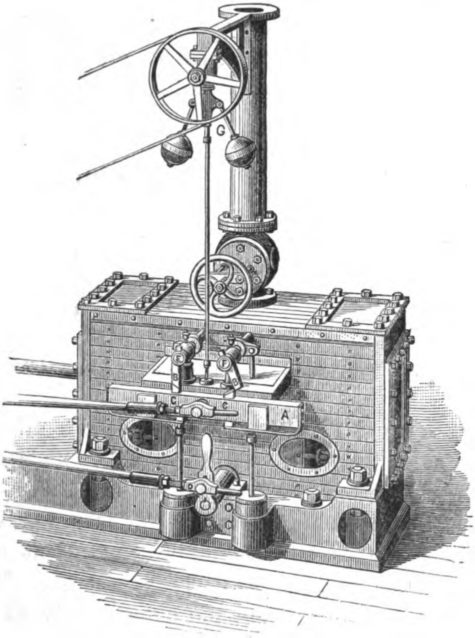


FIG. 99.—Greene Engine.

In the Greene steam-engine (Fig. 99), the valves are four in number, as in the Corliss. The cut-off gear consists of a bar, *A*, moved by the steam-eccentric in a direction parallel with the centre-line of the cylinder and nearly coincident as to time with the piston. On this bar are tappets, *C C*, supported by springs and adjustable in height by the governor, *G*. These tappets engage the arms *B B*, on the ends of rock-shafts, *E E*, which move the steam-valves and remain in contact with them a longer or shorter time, and holding the valve open during a greater or less part of the piston-stroke, as the governor permits the tappets to rise with diminishing engine-speed, or forces them down as speed increases. The exhaust-valves are moved by an independent eccentric rod, which is itself moved by an eccentric set, as is usual with the Corliss and with other engines generally, at right angles with the crank. This engine, in consequence of the independence of the steam-eccentric, and of the contemporary movement of steam valve-motion and steam-piston, is capable of cutting off at any point from beginning to nearly the end of the stroke. The usual arrangement, by which steam and exhaust valves are moved by the same eccentric, only permits expansion with the range from the beginning to half-stroke. In the Corliss engine the latter construction is retained, with the object, in part, of securing a means of closing the valve by a "positive motion," should, by any accident, the closing not be effected by the weight or spring usually relied upon.

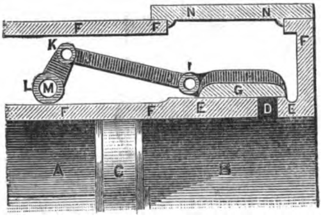


FIG. 100.—Thurston's Greene Engine Valve-Gear.

This was placed in a furnace kept at a high temperature by a forced combustion. Safety-valves loaded respectively to 425 and 550 pounds per square inch were placed on each of two of the steam-pipes.

Perkins used the steam generated under these great pressures in a little engine having a piston 2 inches in diameter and a stroke of 1 foot. It was rated at 10 horse-power.[1]

In the year 1827, Perkins had attained working pressures, in a single-acting, single-cylinder engine, of upward of 800 pounds per square inch. At pressures exceeding 200 pounds, he had much trouble in securing effective lubrication, as all oils charred and decomposed at the high temperatures then unavoidably encountered, and he finally succeeded in evading this seemingly insurmountable obstacle by using for rubbing parts a peculiar alloy which required no lubrication, and which became so beautifully polished, after some wear, that the friction was less than where lubricants were used. At these high pressures Perkins seems to have met with no other serious difficulty. He condensed the exhaust-steam and returned it to the boiler, but did not attempt to create a vacuum in his condenser, and therefore needed no air-pump. Steam was cut off at one-eighth stroke.

In the same year, Perkins made a compound engine on the Woolf plan, and adopted a pressure of 1,400 pounds, ex-

---

[1] It was when writing of this engine that Stuart wrote, in 1824: "Judging from the rapid strides the steam-engine has made *during the last forty years* to become a universal first-mover, and from the experience that has arisen from that extension, we feel convinced that every invention which diminishes its size without impairing its power brings it a step nearer to the assistance of the 'world's great labourers,' the husbandman and the peasant, for whom, as yet, it performs but little. At present, it is made occasionally to tread out the corn. What honours await not that man who may yet direct its mighty power to plough, to sow, to harrow, and to reap!" The progress of the steam-engine during those forty years does not to-day appear so astounding. The sentiment here expressed has lost none of its truth, nevertheless.

after it has become complete, so far as supplying it with all essential parts can complete it.

In the figure, *A* is the cylinder, taking steam from the boiler through the steam-passage, *M*. The steam is first admitted above the piston, *B*, driving it rapidly downward and raising the pump-rod, *E*. At an early period in the stroke the admission of steam is checked by the sudden closing of the induction-valve at *M*, and the stroke is completed under the action of expanding steam assisted by the inertia of the heavy parts already in motion. The necessary weight and inertia is afforded, in many cases, where the engine is applied to the pumping of deep mines, by the

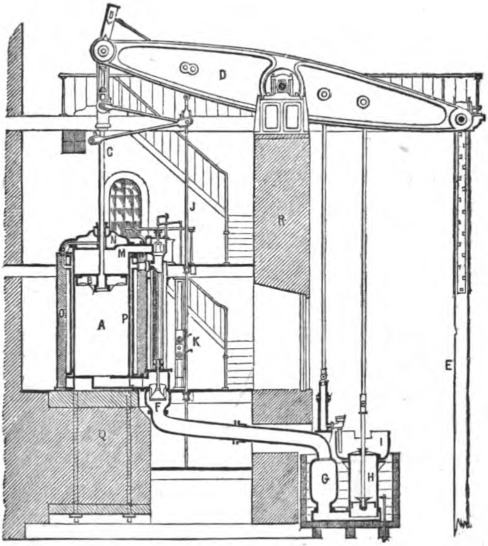


FIG. 101.—Cornish Pumping-Engine, 1878. Section.

lever, *L H*, connected to the pump-buckets by links, *I K*. Steam exhausted from the small cylinder, *A*, is further expanded in the large cylinder, *B*, and thence goes to the condenser, *C*. The valves, *N M*, are moved by the valve-gear, *L*, which is actuated by the piston-rod of a similar pair of cylinders placed by the side of the first. These

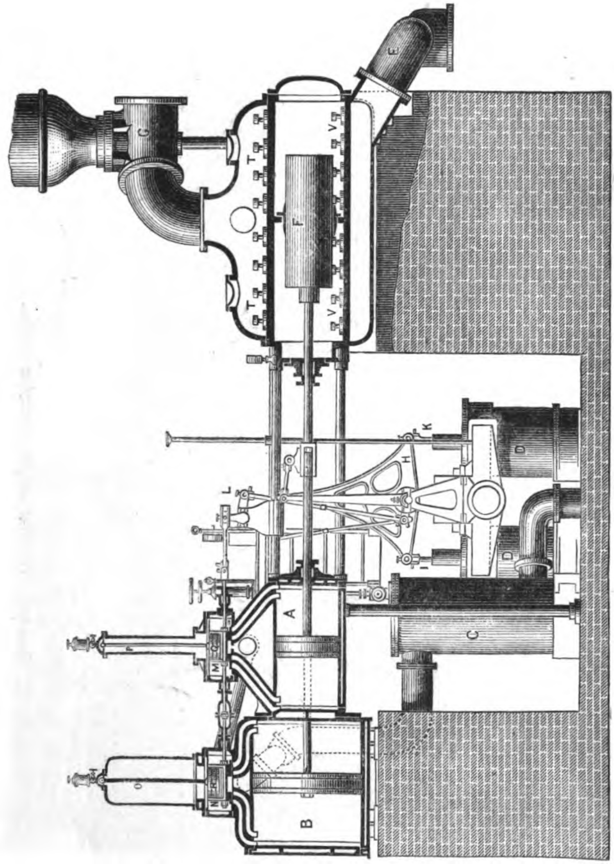


FIG. 108.—The Worthington Pumping-Engine, 1876. Section.

the piston-rod of the other, it is seen that the two engines must work alternately, the one making a stroke while the other is still, and then itself stopping a moment while the latter makes its stroke.

Water enters the pump through the induction-pipe, *E*, passes into the pump-barrel through the valves, *V V*, and issues through the eduction-valves, *T T*, and goes on to the "mains" by the pipe, *G*, above which is seen an air-chamber, which assists to preserve a uniform pressure on that side the pump. This engine works very smoothly and quietly, is cheap and durable, and has done excellent duty.

Beam pumping-engines are now almost invariably built with crank and fly-wheel, and very frequently are compound engines. The accompanying illustration represents an engine of the latter form.

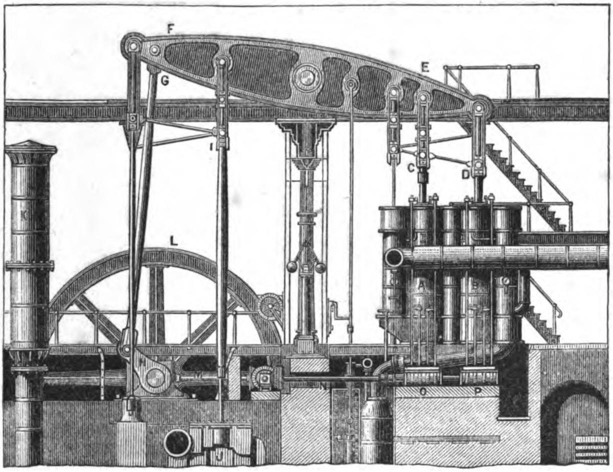


FIG. 105.—Double-Cylinder Pumping-Engine, 1878.

A and *B* are the two steam-cylinders, connected by links and parallel motion, *C D*, to the great cast-iron beam, *E F*. At the opposite end of the beam, the connecting-rod, *G*, turns a crank, *H*, and fly-wheel, *L M*, which regulates the motion of the engine and controls the length of stroke, averting all danger of accident occurring in consequence of the piston striking either cylinder-head. The beam is carried on handsomely-shaped iron columns, which, with cylinders, pump, and fly-wheel, are supported by a

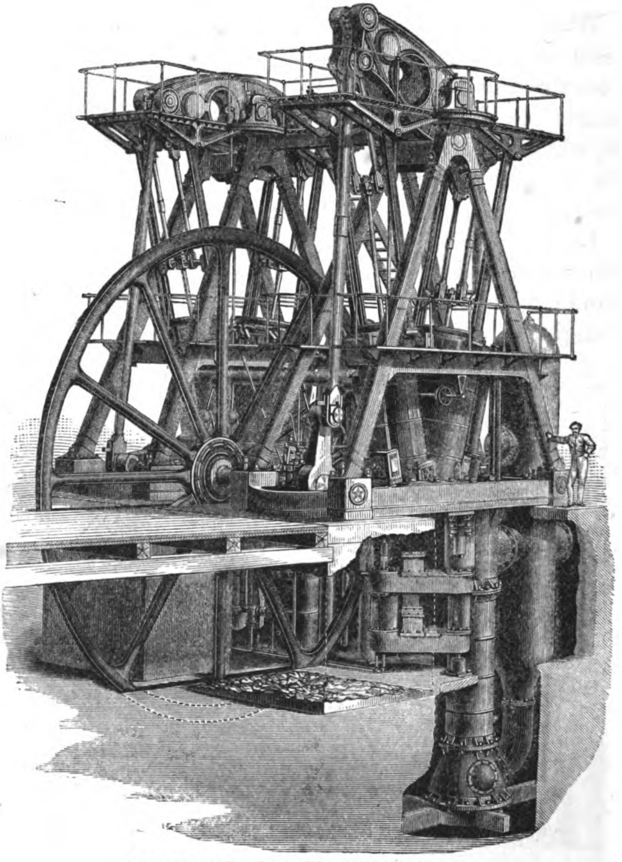


FIG. 106.—The Lynn Water-Works Engine.

substantial stone foundation. The pump-rod, *I*, works a double-acting pump, *J*, and the resistance to the issuing water is rendered uniform by an air-chamber, *K*, within which the water rises and falls when pressures tend to vary greatly. A revolving shaft, *N*, driven from the fly-wheel shaft, carries cams, *O P*, which move the lifting-rods seen directly over them and the valves which they actuate. Between the steam-cylinders and the columns which carry the beams is a well, in which are placed the condenser and air-pump. Steam is carried at 60 or 80 pounds pressure, and expanded from 6 to 10 times.

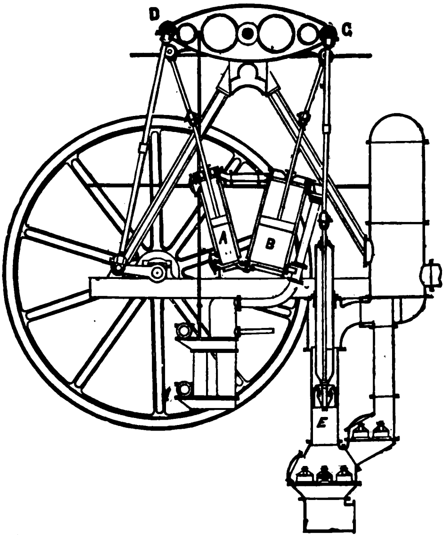


FIG. 107.—The Leavitt Pumping-Engine.

A later form of double-cylinder beam pumping-engine is that invented and designed by E. D. Leavitt, Jr., for the Lynn (Mass.) Water-Works, and shown in Figs. 106 and 107. The two cylinders are placed one on each side the centre of the beam, and are so inclined that they may be coupled to opposite ends of it, while their lower ends are placed close together. At their upper ends a valve is placed at each end of the connecting steam-pipe. At their lower ends a single valve serves as exhaust-valve to the high-pressure and as steam-valve to the low-pressure cylinder. The pistons move in opposite directions, and steam is exhausted from the high-pressure cylinder directly into the nearer end of the low-pressure cylinder. The pump, of the "Thames-Ditton" or "bucket-and-plunger" variety, takes a full supply of water on the down-stroke, and discharges half when rising and half when descending again. The duty of this engine is reported by a board of engineers as 103,923,215 foot-pounds for every 100 pounds of coal burned. The duty of a moderately good engine is usually considered to be from 60 to 70 millions. This engine has steam-cylinders of 17½ and 36 inches diameter respectively, with a stroke of 7 feet. The pump had a capacity of about 195 gallons, and delivered 96 per cent. Steam was carried at a pressure of 75 pounds above the atmosphere, and was expanded about 10 times. Plain horizontal tubular boilers were used, evaporating 8.58 pounds of water from 98° Fahr. per pound of coal.

STEAM-BOILERS.—The steam supplied to the forms of stationary engine which have been described is generated in steam-boilers of exceedingly varied forms. The type used is determined by the extent to which their cost is increased in the endeavour to economize fuel by the pressure of steam carried, by the greater or less necessity of providing against risk of explosion, by the character of the feed-water to be used, by the facilities which may exist for keeping in good repair, and even by the character of the men in whose hands the apparatus is likely to be placed.

As has been seen, the changes which have marked the growth and development of the steam-engine have been accompanied by equally marked changes in the forms of the steam-boiler. At first, the same vessel served the distinct purposes of steam-generator and steam-engine. Later, it became separated from the engine, and was then specially fitted to perform its own peculiar functions; and its form went through a series of modifications under the action of the causes already stated.

When steam began to be usefully applied, and considerable pressures became necessary, the forms given to boilers were approximately spherical, ellipsoidal, or cylindrical. Thus the boilers of De Caus (1615) and of the Marquis of Worcester (1663) were spherical and cylindrical; those of Savery (1698) were ellipsoidal and cylindrical. After the invention of the steam-engine of Newcomen, the pressures adopted were again very low, and steam-boilers were given irregular forms until, at the beginning of the present century, they were again of necessity given stronger shapes. The material was at first frequently copper; it is now usually wrought-iron, and sometimes steel.

The present forms of steam-boilers may be classified as plain, flue, and tubular boilers. The plain cylindrical or common cylinder boiler is the only representative of the first class in common use. It is perfectly cylindrical, with heads either flat or hemispherical. There is usually attached to the boiler a "steam-drum" (a small cylindrical vessel), from which the steam is taken by the steam-pipe. This enlargement of the steam-space permits the mist, held in suspension by the steam when it first rises from the surface of the water, to separate more or less completely before the steam is taken from the boiler.

Flue-boilers are frequently cylindrical, and contain one or more cylindrical flues, which pass through from end to end, beneath the water-line, conducting the furnace-gases, and affording a greater area of heating-surface than can be obtained in the plain boiler. They are usually from 30 to 48 inches in diameter, and one foot or less in length for each inch of diameter. Some are, however, made 100 feet and more in length. The boiler is made of iron $\frac{1}{4}$ to $\frac{3}{8}$ of an directly to the smoke-stack. Strength, compactness, great steaming capacity, fair economy, moderate cost, and convenience of combination with the running parts, are secured by the adoption of this form. It is frequently used also for portable and stationary engines. It was invented in France by M. Séguin, and in England by Booth, and used by George Stephenson at about the same time—1828 or 1829.

Since the efficiency of a steam-boiler depends upon the extent of effective heating-surface per unit of weight of fuel burned in any given time—or, ordinarily, upon the ratio of the areas of heating and grate surface—peculiar expedients are sometimes adopted, having for their object the increase of heating-surface, without change of form of boiler and without proportionate increase of cost.

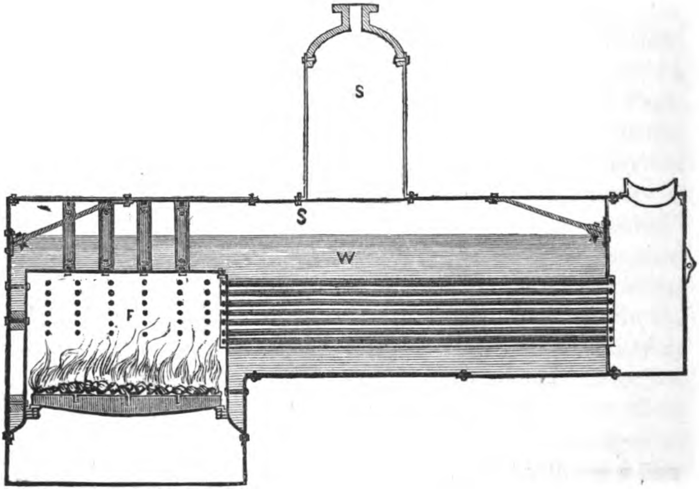


FIG. 109.—Stationary "Locomotive" Boiler.

One of these methods is that of the use of Galloway conical tubes (Fig. 110). These are very largely used in

A committee of the American Institute, of which the author was chairman, in 1871, examined several boilers of this and the ordinary type, and tested them very carefully. They reported that they felt "confident that the introduction of this class of steam-boilers will do much toward the removal of the cause of that universal feeling of distrust which renders the presence of a steam-boiler so objectionable in every locality. The difficulties in thoroughly inspecting these boilers, in regulating their action, and other faults of the class, are gradually being overcome, and the committee look forward with confidence to the time when their use will become general, to the exclusion of older and more dangerous forms of steam-boilers."

The economical performance of these boilers with a similar ratio of heating to grate surface is equal to that of other kinds. In fact, they are usually given a somewhat higher ratio, and their economy of fuel frequently exceeds that of the other types. Their principal defect is their small capacity for steam and water, which makes it extremely difficult to obtain steady steam-pressure. Where they are employed, the feed and draught should be, if possible, controlled by automatic attachments, and the feed-water heated to the highest attainable temperature. Their satisfactory working depends, more than in other cases, on the ability of the fireman, and can only be secured by the exercise of both care and skill.

Many forms of these boilers have been devised. Walter Hancock constructed boilers for his steam-carriage of flat plates connected by stay-bolts, several such sections composing the boiler; and about the same time (1828) Sir Goldworthy Gurney constructed for a similar purpose boilers consisting of a steam and a water reservoir, placed one above the other, and connected by triangularly-bent water-tubes exposed to the heat of the furnace-gases. Jacob Perkins made many experiments looking to the employment of very high steam-pressures, and in 1831 patented a boiler of this class, in which the heating-surfaces nearest the fire were composed of iron tubes, which tubes also served as grate-bars. The steam and water space was principally comprised within a comparatively large chamber, of which the walls were secured by closely distributed stay-bolts. For extremely high pressures, boilers composed only of tubes were used. Dr. Ernst Alban described the boiler already referred to, and its construction and operation, and stated that he had experimented with pressures as high as 1,000 pounds to the square inch.

The Harrison steam-boiler, which has been many years in use in the United States, consists of several sections, each of which is made up of hollow globes of cast-iron, communicating with each other by necks cast upon the spheres, and fitted together with faced joints. Long bolts, extending from end to end of each row, bind the spheres together. (*See* Fig. 111.)

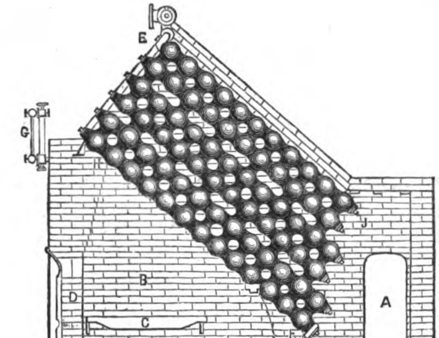


FIG. 111.—Harrison's Sectional Boiler.

An example of another modern type in extensive use is given in Fig. 112, a semi-sectional boiler, which consists of a series of inclined wrought-iron tubes, connected by T-

Attempts have been made to adapt sectional boilers to marine engines; but very little progress has yet been made in their introduction. The Root sectional boiler (Fig. 113), an American design, which is in extensive use in the United States and Europe, has also been experimentally placed in service on shipboard. Its heating-surface consists wholly of tubes, which are connected by a peculiarly formed series of caps; the joints are made tight with rubber "grummets."

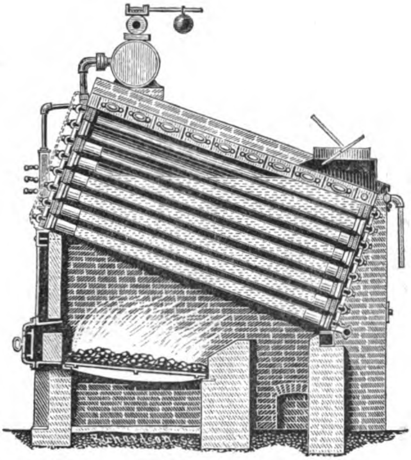


FIG. 113.—Root Sectional Boiler.

SECTION II.—PORTABLE AND LOCOMOTIVE ENGINES.

Engines and boilers, when of small size, are now often combined in one structure which may be readily transported. Where they have a common base-plate simply, as in Fig. 114, they are called, usually, "semi-portable engines." These little engines have some decided advantages. Being attached to one base, the combined engine and boiler is and are intended to be worked at 150 pounds pressure per inch. They are fitted with a baffle-plate and circulating-pipe, to prevent priming, and also with a fusible plug, which will melt and prevent the crown-sheet of the boiler burning, if the water gets low.

Another illustration of this form of engine, as built in small sizes, is seen below. The peculiarity of this engine is, that the cylinder is placed in the top of the boiler, which is upright. By this arrangement the engine is constantly drawing from the boiler the hottest and driest steam, and there is thus no liability of serious loss by condensation, which is rapid, even in a short pipe, when the engine is separate from the boiler.

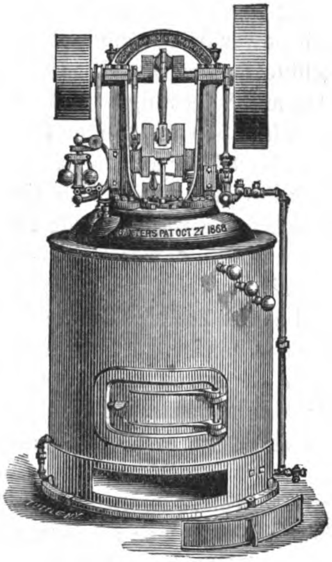


FIG. 115.—Semi-Portable Engine, 1878.

The engine illustrated is rated at 10 horse-power, and makers are always expected to guarantee their machines to learned by an inspection of these engines, and by observation of the method of managing them at the test-trial. The engines are usually very carefully designed. The cylinders are nicely proportioned to their work, and their pistons travel at high speed. Their valve-gear consists usually of a plain slide-valve, supplemented by a separate expansion-slide, driven by an independent eccentric, and capable of considerable variation in the point of cut-off. This form of expansion-gear is very effective—almost as much so as a drop cut-off—at the usual grade of expansion, which is not far from four times. The governor is usually attached to a throttle-valve in the steam-pipe, an arrangement which is not the best possible under variable loads, but which produces no serious loss of efficiency when the engine is driven, as at competitive trials, under the very uniform load of a Prony strap-brake and at very nearly the maximum capacity of the machine. The most successful engines have had steam-jacketed cylinders — always an essential to maximum economy—with high steam and a considerable expansion. The boilers are strongly made, and are, as are also all other heated surfaces, carefully clothed with non-conducting material, and well lagged over all. The details are carefully proportioned, the rods and frames are strong and well secured together, and the bearings have large rubbing-surfaces. The connecting-rods are long and easy-working, and every part is capable of doing its work without straining and with the least friction.

In handling the engines at the competitive trial, most experienced and skillful drivers are selected. The difference between the performances of the same engine in different hands has been found to amount to from 10 to 15 per cent., even where the competitors were both considered exceptionally skillful men. In manipulating the engine, the fires are attended to with the utmost care; coal is thrown upon them at regular and frequent intervals, and a uniform depth of fuel and a perfectly clean fire are secured. The sides and corners of the fire are looked after with especial care. The fire-doors are kept open the least possible time; not a square inch of grate-surface is left unutilized, and every pound of coal gives out its maximum of calorific power, and in precisely the place where it is needed. Feed-water is supplied as nearly as possible continuously, and with the utmost regularity. In some cases the engine-driver stands by his engine constantly, feeding the fire with coal in handfuls, and supplying the water to the heater by hand by means of a cup. Heaters are invariably used in such cases. The exhaust is contracted no more than is absolutely necessary for draught. The brake is watched carefully, lest irregularity of lubrication should cause oscillation of speed with the changing resistance. The load is made the maximum which the engine is designed to drive with economy. Thus all conditions are made as favourable as possible to economy, and they are preserved as invariable as the utmost care on the part of the attendant can make them.

These trials are usually of only three or five hours' duration, and thus terminate before it becomes necessary to clean fires. The following are results obtained at the trial of engines which took place in July, 1870, at the Oxford Agricultural Fair:

MAKERS' NAME AND RESIDENCE.	CYLINDERS.			HORSE-POWER.				
	Number.	Diameter.	Stroke.	Nominal.	Dynamometric.	Point of cut-off.	Revolutions per minute.	Pounds coal per horse-power per hour.
		Inches.	In.					
Clayton, Shuttleworth & Co., Lincoln....	1	7	12	4	4.42	.....	121.65	3.73
Brown & May, Devizes	1	7 3-16	12	4	4.19	11.48	125.65	4.44
Reading Iron-Works Company, Reading.	1	5 3-4	14	4	4.16	.....	145.7	4.65

ton, making 125 revolutions per minute, and has 9 square feet of grate-surface and 288 feet of heating-surface. It weighs about 4½ tons. Steam is carried at 125 pounds.

In the class of engines just described, the draught is obtained by the blast of the exhaust-steam which is led into the chimney. Such engines are now sold at from $120 to $150 per horse-power, according to size and quality, the smaller engines costing most. The usual consumption of fuel is from 4 to 6 pounds per hour and per horse-power, burning from 15 to 20 pounds on each square foot of grate, and each pound evaporating about 8 pounds of water. A usual weight is, for the larger sizes, 500 pounds per horse-power.

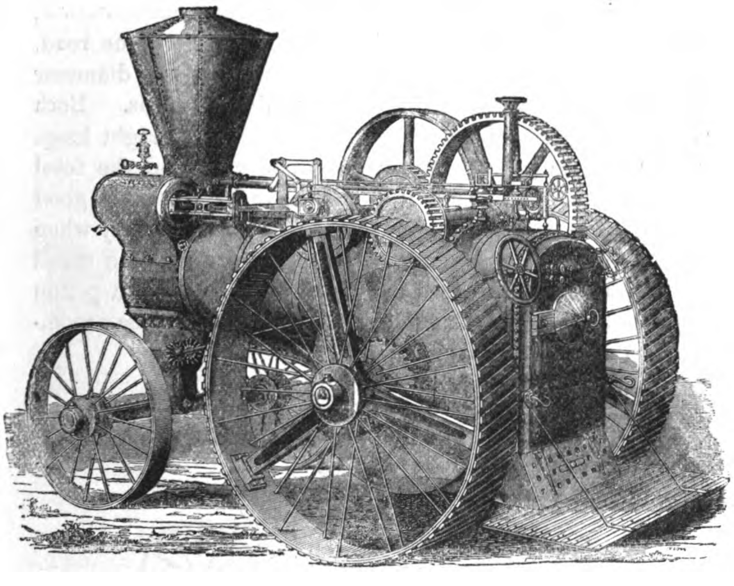


FIG. 117.—The Thrashers' Road-Engine, 1878.

These engines are sometimes arranged to propel them-

Weight of engine, complete, 5 tons 4 cwt.	11,648	pounds.
Steam-cylinder—diameter	7¾	inches.
Stroke of piston	10	inches.
Revolution of crank to one of driving-wheels	17	
Driving-wheels—diameter	60	inches.
" breadth of tire	10	inches.
" weight, each	450	pounds.
Boiler—length over all	8	feet.
" diameter of shell	30	feet.
" thickness of shell	$\frac{7}{16}$	inch.
" fire-box sheets, outside, thickness	½	inch.
Load on driving-wheels, 4 tons 10 cwt.	10,080	pounds.

The boiler was of the ordinary locomotive type, and the engine was mounted upon it, as is usual with portable engines.

The steam-cylinder was steam-jacketed, in accordance with the most advanced practice here and abroad. The crank-shaft and other wrought-iron parts subjected to heavy strains were strong and plainly finished. The gearing was of malleableized cast-iron, and all bearings, from crank-shaft to driving-wheel, on each side, were carried by a single sheet of half-inch plate, which also formed the sides of the fire-box exterior.

The following is a summary of the conclusions deduced by the author from the trial, and published in the *Journal of the Franklin Institute:* A traction-engine may be so constructed as to be easily and rapidly manœuvred on the common road; and an engine weighing over 5 tons may be turned continuously without difficulty on a circle of 18 feet radius, or even on a road but little wider than the length of the engine. A locomotive of 5 tons 4 hundred-weight has been constructed, capable of drawing on a good road 23,000 pounds up a grade of 533 feet to the mile, at the rate of four miles an hour; and one might be constructed to draw more than 63,000 pounds up a grade of 225 feet to the mile, at the rate of two miles an hour.

It was further shown that the coefficient of traction with heavily-laden wagons on a good macadamized road is not far from .04; the traction-power of this engine is equal to that of 20 horses; the weight, exclusive of the weight of the engine, that could be drawn on a level road, was 163,452 pounds; and the amount of fuel required is estimated at 500 pounds a day. The advantages claimed for the traction-engine over horse-power are: no necessity for a limitation of working-hours; a difference in first cost in favour of steam; and in heavy work on a common road the expense by steam is less than 25 per cent. of the average cost of horse-power, a traction-engine capable of doing the work of 25 horses being worked at as little expense as 6 or 8 horses. The cost of hauling heavy loads has been estimated at 7 cents per ton per mile.

Such engines are gradually becoming useful in steam-ploughing. Two systems are adopted. In the one the engine is stationary, and hauls a "gang" of ploughs by means of a windlass and wire rope; in the other the engine traverses a field, drawing behind it a plough or a gang of ploughs. The latter method has been proposed for breaking up prairie-land.

Thus, thirty years after the defeat of the intelligent, courageous, and persistent Hancock and his coworkers in the scheme of applying the steam-engine usefully on the common road, we find strong indications that, in a new form, the problem has been again attacked, and at least partially solved.

One of the most important of the prerequisites to ultimate success in the substitution of steam for animal power on the highway is that our roads shall be well made. As the greatest care and judgment are exercised, and an immense outlay of capital is considered justifiable, in securing easy grades and a smooth track on our railroad routes, we may readily believe that similar precaution and outlay will be found advisable in adapting the common road to the road-locomotive. It would seem to the engineer that the

They were "self-propellers," and one of them, built for the city of Philadelphia, was sent to that city over the highway, driven by its own engines. The other was built for and used by the New York Fire Department, and did good service for several years. These engines were heavy, but very powerful, and were found to move at good speed under steam

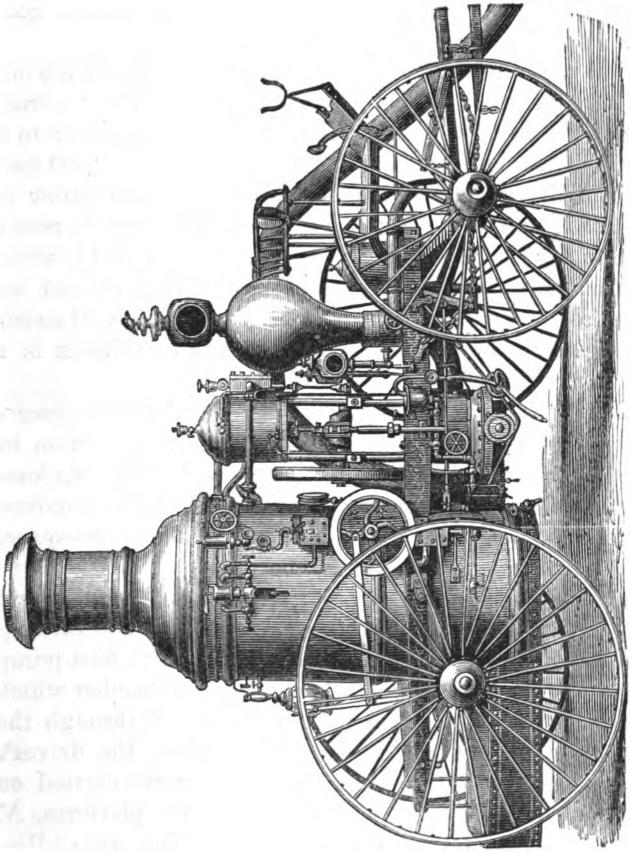


Fig. 120.—The Latta Steam Fire-Engine.

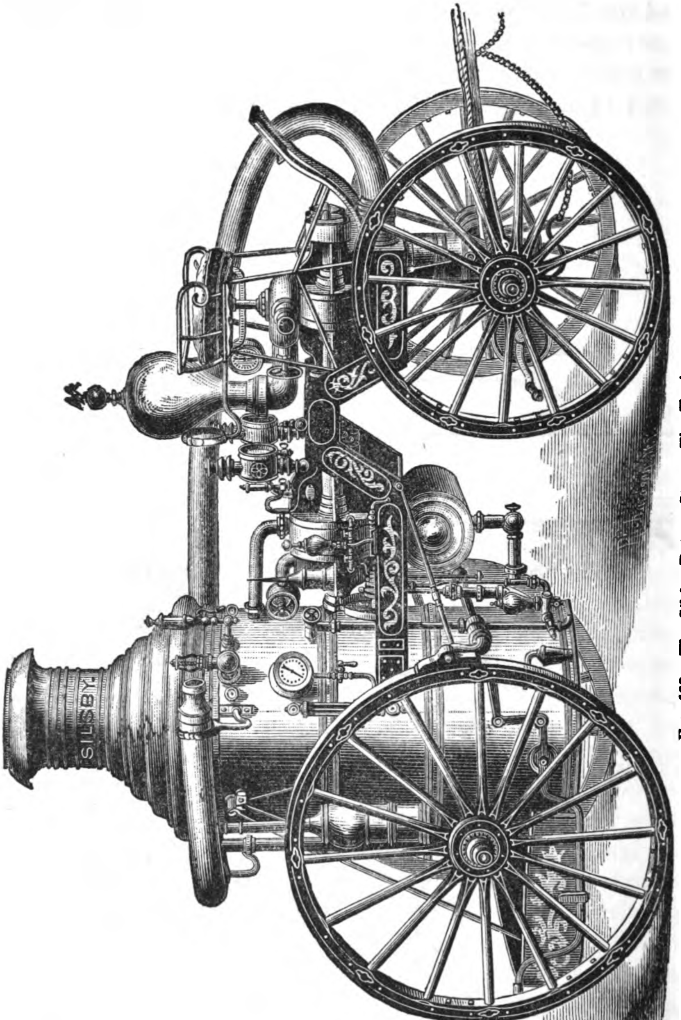


FIG. 122.—The Silsby Rotary Steam Fire-Engine.

have been accompanied by corresponding changes in all branches of railroad-work. The adjustment of parts to each other and proportioning them to their work, the modification of the minor details to suit changes of general dimensions, the improvement of workmanship, and the use of better material, have signalized this latest period. Special forms of engine have been devised for special kinds of work. Small, light tank-engines (Fig. 125), carrying their own fuel and water without "tenders," are used for moving cars about terminal stations and for making up trains; powerful, heavy, slow-moving engines, of large boiler-capacity and with small wheels, are used on steep gradients and for hauling long trains laden with coal and heavy merchandise; and hardly less powerful but quite differently proportioned "express"-engines are used for passenger and mail service.

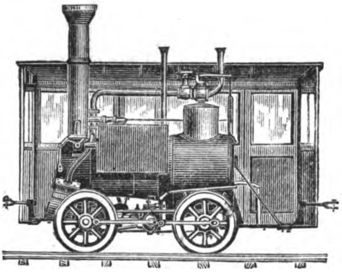


FIG. 125.—Tank-Engine, New York Elevated Railroad.

A peculiar form of engine (Fig. 126) has been designed by Forney, in which the whole weight of engine, tender, coal, and water, is carried by one frame and on one set of wheels, the permanent weight falling on the driving-wheels and the variable load on the truck. These engines have also a comparatively short wheel-base and high pulling-power. The lightest tank-engines of the first class mentioned weigh 8 or 10 tons; but engines much lighter than these having a weight of about 100,000 pounds, which is carried on 12 driving-wheels.

A locomotive has two steam-cylinders, either side by side within the frame, and immediately beneath the forward end of the boiler, or on each side and exterior to the frame. The engines are non-condensing, and of the simplest possible construction. The whole machine is carried upon strong but flexible steel springs. The steam-pressure is usually more than 100 pounds. The pulling-power is generally about one-fifth the weight under most favourable conditions, and becomes as low as one-tenth on wet rails. The fuel employed is wood in new countries, coke in bituminous coal districts, and anthracite coal in the eastern part of the United States. The general arrangement and the proportions of locomotives differ somewhat in different localities. In Fig. 127, a British express-engine, *O* is the boiler, *N* the fire-box, *X* the grate, *G* the smoke-box, and *P* the chimney. *S* is a spring and *R* a lever safety-valve, *T* is the whistle, *L* the throttle or regulator valve, *E* the steam-cylinder, and *W* the driving-wheel. The force-pump, *B C*, is driven from the cross-head, *D*. The frame is the base of the whole system, and all other parts are firmly secured to it. The boiler is made fast at one end, and provision is made for its expansion when heated. Adhesion is secured by throwing a proper

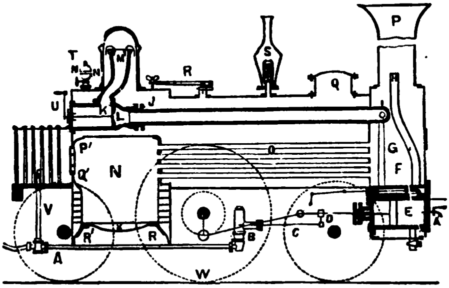


FIG. 127.—British Express Engine.

proportion of the weight upon the driving-wheel, *W.* This is from about 6,000 pounds on standard freight-engines,

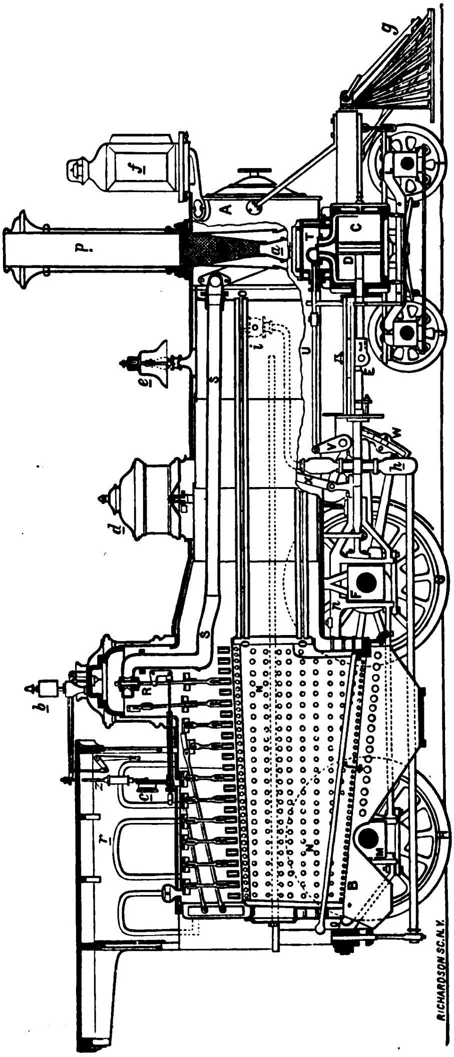


FIG. 128.—The Baldwin Locomotive. Section.

having several pairs of drivers, to 10,000 pounds on passenger-engines, per axle. The peculiarities of the American type (Fig. 128) are the truck, *I J*, or bogie, supporting the forward part of the engine, the system of equalizers, or beams which distribute the weight of the machine equally over the several axles, and minor differences of detail. The cab or house, *r*, protecting the engine-driver and fireman, is an American device, which is gradually coming into use abroad also. The American locomotive is distinguished by its flexibility and ease of action upon even roughly-laid roads. In the sketch, which shows a standard American engine in section, *A B* is the boiler, *C* one of the steam-cylinders, *D* the piston, *E* the cross-head, connected to the crank-shaft, *F*, by the connecting-rod, *G H* the driving-wheels, *I J* the truck-wheels, carrying the truck, *K L*; *M N* is the fire-box, *O O* the tubes, of which but four are shown. The steam-pipe, *R S*, leads the steam to the valve-chest, *T*, in which is seen the valve, moved by the valve-gear, *U V*, and the link, *W*. The link is raised or depressed by a lever, *X*, moved from the cab. The safety-valve is seen at the top of the dome, at *Y*, and the spring-balance by which the load is adjusted is shown at *Z*. At *a* is the cone-shaped exhaust-pipe, by which a good draught is secured. The attachments *b*, *c*, *d*, *e*, *f*, *g*—whistle, steam-gauge, sand-box, bell, head-light, and "cow-catcher"—are nearly all peculiar, either in construction or location, to the American locomotive. The cost of passenger-locomotives of ordinary size is about $12,000; heavier engines sometimes cost $20,000. The locomotive is usually furnished with a tender, which carries its fuel and water. The standard passenger-engine on the Pennsylvania Railroad has four driving-wheels, 5½ feet diameter; steam-cylinders, 17 inches diameter and 2 feet stroke; grate-surface 15½ square feet, and heating-surface 1,058 square feet. It weighs 63,100 pounds, of which .39,000 pounds are on the drivers and 24,100 on the truck. The freight-engine has six driving-

Compound engines of this kind have been used on the French line of railroad from Bayonne to Biarritz. They were designed by Mallet and built at Le Creuzot. The steam-cylinders are of 9½ and 15¾ inches diameter, and of 17¾ inches stroke of piston. The four driving-wheels are 4 feet in diameter, and the total weight of engine is 20 tons. The boiler has 484½ square feet of heating-surface, and is built to carry 10 atmospheres pressure. When hauling trains of 50 tons at 25 miles an hour, these engines require about 15 pounds of good coal per mile.

The total length of the railways in operation in the United States on the 1st day of January, 1877, was 76,640 miles,[1] being an average of one mile of railway for every 600 inhabitants. The railways are as follows:

	Miles.		Miles.		Miles.
Alabama	1,722	Kentucky	1,464	Ohio	4,680
Alaska	0	Louisiana	539	Oregon	251
Arizona	0	Maine	987	Pennsylvania	5,896
Arkansas	787	Maryland	1,092	Rhode Island	182
California	1,854	Massachusetts	1,825	South Carolina	1,352
Colorado	950	Michigan	3,437	Tennessee	1,638
Connecticut	925	Minnesota	2,024	Texas	2,072
Dakota	290	Mississippi	1,028	Utah	486
Delaware	285	Missouri	3,016	Vermont	810
Florida	484	Montana	0	Virginia	1,648
Georgia	2,308	Nebraska	1,181	Washington	110
Idaho	0	Nevada	714	West Virginia	576
Illinois	6,980	New Hampshire	942	Wisconsin	2,575
Indiana	4,072	New Jersey	1,594	Wyoming	459
Indian Territory	281	New Mexico	0		
Iowa	3,937	New York	5,520	Total	76,640
Kansas	3,226	North Carolina	1,371		

In 1873 came the great financial crisis, with its terrible results of interrupted production, poverty, and starvation, and an almost total cessation of the work of building new railroads. The largest number of miles ever built in any one year were constructed in 1872. The greatest mileage is in Illinois, reaching 6,589; the smallest in Rhode Island, 136, and in Washington Territory, 110. The State of Massachusetts has one mile of railroad to 4.86

---

[1] January, 1878, about 80,000 miles.

The railroads in Great Britain comprise over 15,000 miles of track now being worked in the United Kingdom, on which have been expended $2,800,000,000. This sum is equal to five times the amount of the annual value of all the real property in Great Britain, and two-thirds of the national debt. After deducting all the working expenses, the gross net annual revenue of all the roads exceeds by $110,000,000 the total revenue from all sources of Belgium, Holland, Portugal, Denmark, Sweden and Norway. An army of 100,000 officers and servants is in the employ of the companies, and the value of the rolling-stock exceeds $150,000,000.

SECTION III.—MARINE ENGINES.

The changes which have now become completed in the marine steam-engine have been effected at a later date than those which produced the modern locomotive. On the American rivers the modification of the beam-engine since the time of Robert L. Stevens has been very slight. The same general arrangement is retained, and the details are little, if at all, altered. The pressure of steam is sometimes as high as 60 pounds per square inch.

The valves are of the disk or poppet variety, rising and falling vertically. They are four in number, two steam and two exhaust valves being placed at each end of the steam-cylinder. The beam-engine is a peculiarly American type, seldom if ever seen abroad. Fig. 130 is an outline sketch of this engine as built for a steamer plying on the Hudson River. This class of engine is usually adopted in vessels of great length, light draught, and high speed. But one steam-cylinder is commonly used. The cross-head is coupled to one end of the beam by means of a pair of links, and the motion of the opposite end of the beam is transmitted to the crank by a connecting-rod of moderate length. The beam has a cast-iron centre surrounded by a wrought-iron strap of lozenge shape, in which are forged steam-cylinder. The air-pump is placed close beside it, and worked by a rod attached to the beam. Steam-vessels on the Hudson River have been driven by such engines at the rate of 20 miles an hour. This form of engine is remarkable for its smoothness of operation, its economy and durability, its compactness, and the latitude which it permits in the change of shape of the long, flexible vessels in which it is generally used, without injury by "getting out of line."

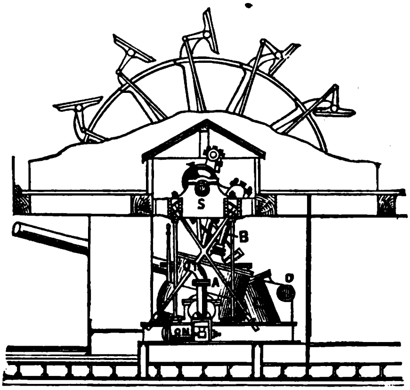


Fig. 181.—Oscillating Engine and Feathering Paddle-Wheel.

For paddle-engines of large vessels, the favourite type, which has been the side-lever engine, is now rarely built. For smaller vessels, the oscillating engine with feathering paddle-wheels is still largely employed in Europe. This style of engine is shown in Fig. 131. It is very compact, light, and moderately economical, and excels in simplicity. The usual arrangement is such that the feathering-wheel has the same action upon the water as a radial wheel of double diameter. This reduction of the diameter of the wheel, while retaining maximum effectiveness, permits a high speed of engine, and therefore less weight, volume, and cost. The smaller wheel-boxes, by offering less resistance to the wind, retard the progress of the vessel less than those average speed is about 14 knots on its route of 160 miles. The coal required to supply the furnaces of such a vessel and with such machinery would be about 3 tons per hour,

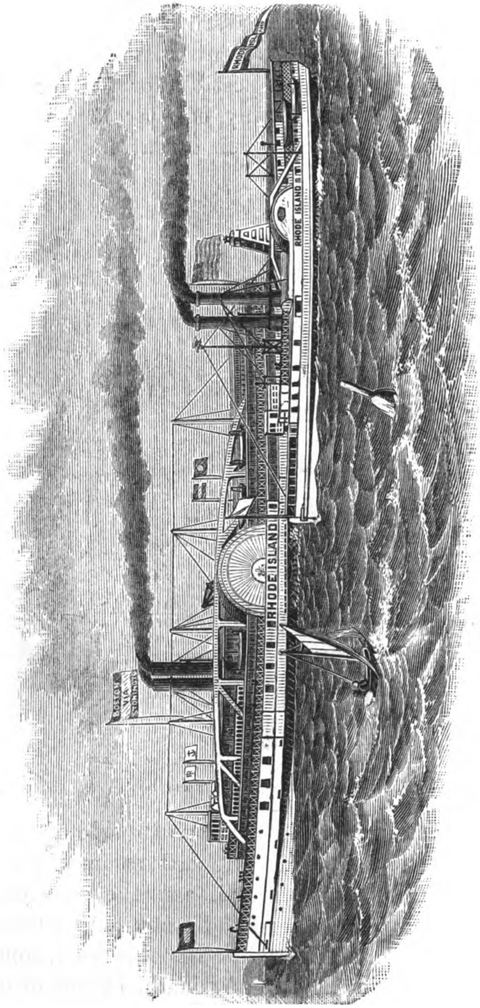


Fig. 132.—The Two Rhode Islands, 1836-1876.

or a little over 2¼ pounds per horse-power. The construction of such a vessel occupies, usually, about a year, and costs a quarter of a million dollars.

The non-condensing direct-acting engine is used principally on the Western rivers, driven by steam of from 100 to 150 pounds pressure, and exhausts its steam into the atmosphere. It is the simplest possible form of direct-acting engine. The valves are usually of the "poppet" variety, and are operated by cams which act at the ends of long levers having their fulcra on the opposite side of the valve, the stem of which latter is attached at an intermediate point. The engine is horizontal, and the connecting-rod directly attached to cross-head and crank-pin without intermediate mechanism. The paddle-wheel is used, sometimes as a stern-wheel, as in the plan of Jonathan Hulls of one and

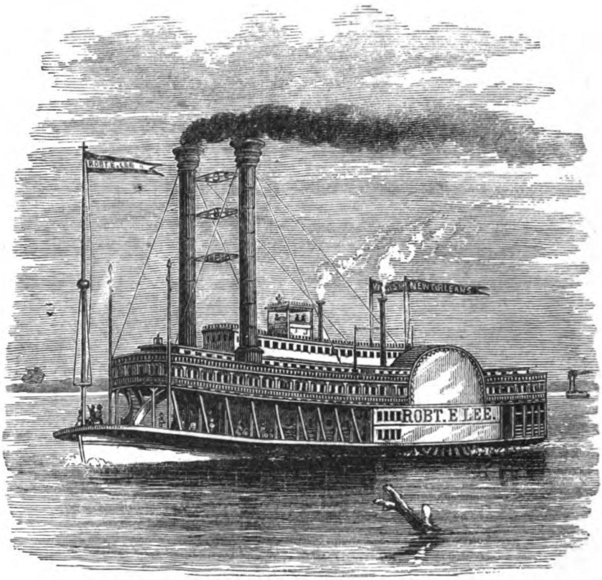


Fig. 138.—A Mississippi Steamboat.

boats driven by steam-power is of comparatively recent date, but their use is rapidly increasing. Those first built were heavy, slow, and complicated; but, profiting by experience, light and graceful boats are now built, of remarkable swiftness, and having such improved and simplified machinery that they require little fuel and can be easily

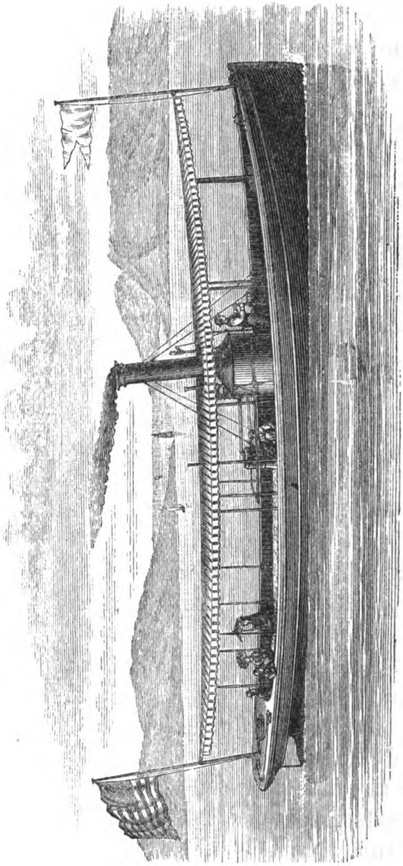


FIG. 134.—Steam-Launch, New York Steam-Power Company.

F is the cross-head guide. The eccentrics, *G*, operate the valve, which is of the "three-ported variety," by a Stephenson link. Reversing is effected by the hand-wheel, *C*, which, by means of a gear, *m*, and a rack, *k*, elevates and depresses the link, and thus reverses the valve.

The trunk-engine, in which the connecting-rod is attached directly to the piston and vibrates within a trunk or cylinder secured to the piston, moving with it, and extending outside the cylinder, like an immense hollow piston-rod, is frequently used in the British navy. It has rarely been adopted in the United States.

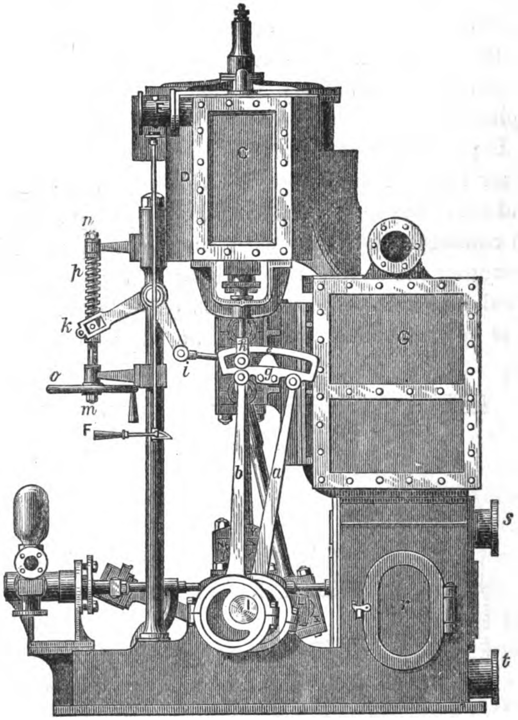


FIG. 137.—Compound Marine Engine. Side Elevation.

In nearly all steam-vessels which have been built for the merchant service recently, and in some naval vessels, the compound engine has been adopted. Figs. 137 and 138 represent the usual form of this engine. Here *A A*, *B B* are the small and the large, or the high-pressure and the low-pressure cylinders respectively. *C C* are the valve-chests. *G G* is the condenser, which is invariably a surface-condenser. The condensing water is sometimes directed around the tubes contained within the casing, *G G*, while the steam is exhausted around them and among them,

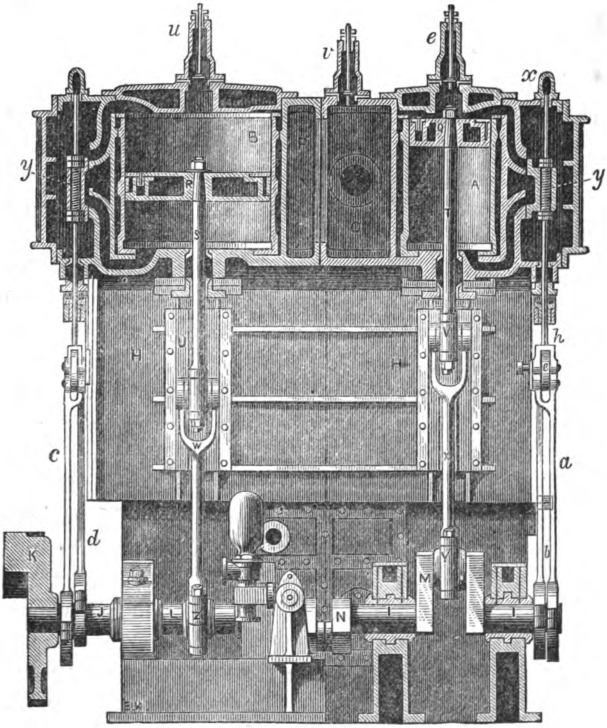


Fig. 188.—Compound Marine Engine. Front Elevation and Section.

pump, inside the frame, at *T.* The feed-pump and the bilge-pumps are driven from the cross-head of the air-pump.

The successful introduction of the double-cylinder engine was finally accomplished by the exertions of a few engineers, who were at once intelligent enough to understand its advantages, and energetic and enterprising enough to push it forward in spite of active opposition, and powerful enough, pecuniarily and in influence, to succeed. The most active and earnest of these eminent men was John Elder, of the firm of Randolph, Elder & Co., subsequently John Elder & Co., of Glasgow.[1]

John Elder.

Elder was of Scotch descent. His ancestors had, for

---

[1] *Vide* "Memoir of John Elder," W. J. M. Rankine, Glasgow, 1871.

C. E. Emery reports the United States revenue-steamer Hassler, designed by him, to have given an ordinary seagoing performance which is probably fully equal to anything yet accomplished. The Hassler is a small steamer, of but 151 feet in length, 24½ feet beam, and 10 feet draught. The engines have steam-cylinders 18.1 and 28 inches diameter, respectively, and of 28 inches stroke of piston, indicating 125 horse-power; with steam at 75 pounds pressure, and at a speed of but 7 knots, the coal consumed was but 1.87 pound per horse-power per hour.

The committee of the British Admiralty on designs of ships-of-war have reported recently: "The carrying-power of ships may certainly be to some extent increased by the adoption of compound engines in her Majesty's service. Its use has recently become very general in the mercantile marine, and the weight of evidence in favour of the large economy of fuel thereby gained is, to our minds, overwhelming and conclusive. We therefore beg earnestly to recommend that the use of compound engines may be generally adopted in ships-of-war hereafter to be constructed, and applied, whenever it can be done with due regard to economy and to the convenience of the service, to those already built."

The forms of screws now employed are exceedingly diverse, but those in common use are not numerous. In naval vessels it is common to apply screws of two blades, that they may be hoisted above water into a "well" when the vessel is under sail, or set with the two blades directly behind the stern-post, when their resistance to the forward motion of the vessel will be comparatively small. In other vessels, and in the greater number of full-power naval vessels, screws of three or four blades are used.

The usual form of screw (Fig. 139) has blades of nearly equal breadth from the hub to the periphery, or slightly widening toward their extremities, as is seen in an exaggerated degree in Fig. 140, representing the form adopted for tug-boats, where large surface near the extremity is more generally used than in vessels of high speed running free. In the Griffith screw, which has been much used, the hub is globular and very large. The blades are secured to the hub by flanges, and are bolted on in such a manner that their position may be changed slightly if desired. The blades are shaped like the section of a pear, the wider part being nearest the hub, and the blades tapering rapidly toward their extremities. A usual form is intermediate between the last, and is like that shown in Fig. 141, the hub being sufficiently enlarged to permit the blades to be attached as in the Griffith screw, but more nearly cylindrical, and the blades having nearly uniform width from end to end.

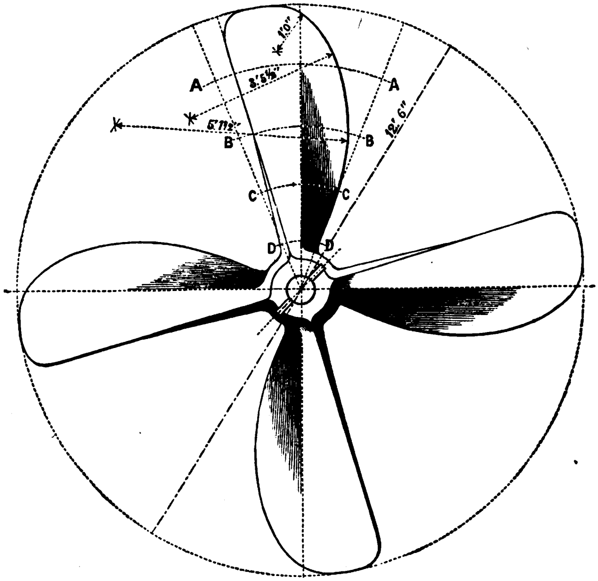


Fig. 189.—Screw-Propeller.

The pitch of a screw is the distance which would be traversed by the screw in one revolution were it to move through the water without slip ; i. e., it is double the distance *C D*, Fig. 140. *C D′* represents the helical path of the extremity of the blade *B*, and *O E F H K* is that of the blade *A*. The proportion of diameter to the pitch of the screw is determined by the speed of the vessel. For low speed the pitch may be as small as $1\frac{1}{4}$ the diameter. For vessels of high speed the pitch is frequently double the diameter. The diameter of the screw is made as great as possible, since the slip decreases with the increase of the area of screw-disk. Its length is usually about one-sixth of the diameter. A greater length produces loss by increase of surface causing too great friction, while a shorter screw does not fully utilize the resisting power of the cylinder of water within which it works, and increased slip causes waste of power. An empirical value for the probable slip in vessels of good shape, which is closely approximate usually, is $S = 4\frac{M}{A}$, in which S is the slip per cent., and M and A are the areas of the midship section and of the screw-disk in square feet.

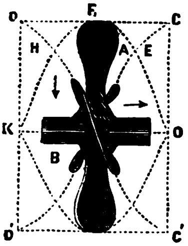


FIG. 140.—Tug-boat Screw.

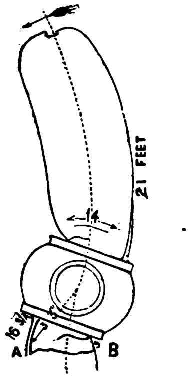


FIG. 141.—Hirsch Screw.

The engines are compound, with two steam-cylinders of 51 inches and two of 88 inches diameter, and a stroke of piston of 4½ feet. The condensing water is sent through the surface-condensers by circulating-pumps driven by their own engines. Ten boilers furnish steam to these engines, each having a diameter of 13 feet, a length of 13½ feet, and a thickness of "shell" of $\frac{13}{16}$ inch. Each has three furnaces, and contains 204 tubes of an outside diameter of 3¼ inches. All together, they have 520 square feet of grate-surface and 17,000 square feet of heating-surface. The area of cooling-surface in the condensers is 10,000 square feet. The machinery is proportioned to develop 4,000 horse-power at 55 revolutions per minute, with steam of 60 pounds pressure, expanding down to 10 pounds before being exhausted into the condenser. The screw has been already illustrated (Fig. 141). It is four-bladed, 20¼ feet in diameter, and has a pitch of 30 feet. This steamer has made 15.8 knots per hour, equal to 19 statute miles, and burns from 40 to 80 tons of coal per day, according to the speed and the state of the weather.

The most successful steam-vessels in general use are these screw-steamers of transoceanic lines. Those of the transatlantic lines, usually, are from 350 to 450 feet long, generally propelled from 12 to 15 knots (14 to 17½ miles) an hour, by engines of from 3,000 to 4,000 horse-power, consuming from 70 to 100 tons of coal a day, and crossing the Atlantic in from eight to ten days. These vessels are now invariably fitted with the compound engine and surface-condensers. One of these vessels, the Germanic, has been reported at Sandy Hook, the entrance to New York Harbor, in 7 days 11 hours 37 minutes from Queenstown—a distance, as measured by the log and by observation, of 2,830 miles. Another steamer, the Britannic, has crossed the Atlantic in 7 days 10 hours and 53 minutes. These vessels are of 5,000 tons burden, of 750 "nominal" horse-power (probably 5,000 actual).

The modern steamship is as wonderful an illustration of ingenuity and skill in all interior arrangements as in size, power, and speed. The size of sea-going steamers has be-

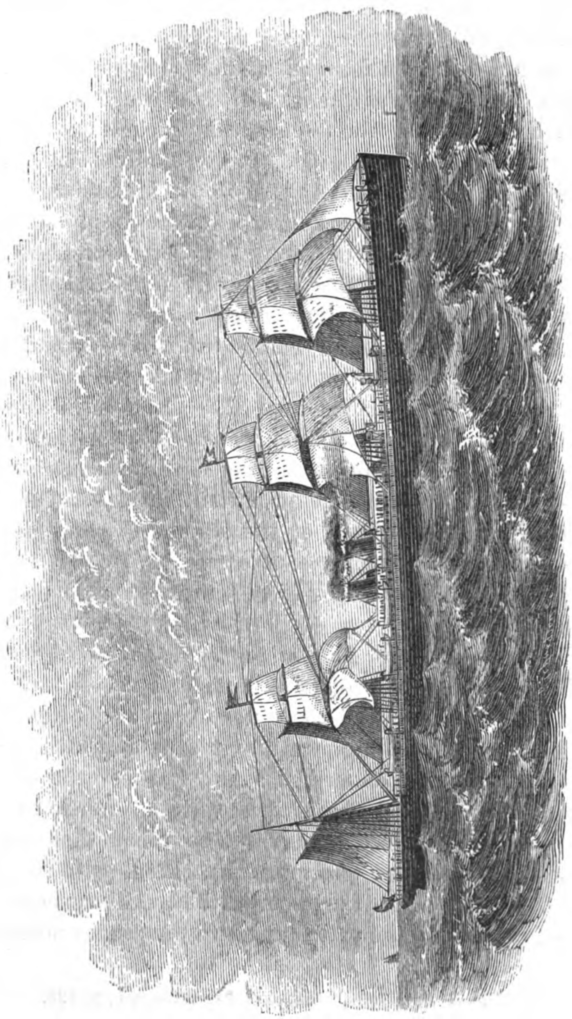


Fig. 144.—The Modern Steamship.

attack than was the last. The fact that the direction of progress in naval science and architecture is plainly perceivable, and that upon its study may be based a fair estimate of the character and relative distribution of several classes of vessels, seems to have been appreciated by very few.

In the year 1870 the writer proposed[1] a classification of vessels other than torpedo-vessels, which has since been also proposed in a somewhat modified form by Mr. J. Scott Russell.[2] The author then remarked that the increase so rapidly occurring in weight of ordnance and of armour, and in speed of war-vessels, would probably soon compel a division of the vessels of every navy into three classes of ships, exclusive of torpedo-vessels, one for general service in time of peace, the others for use only in time of war.

"The first class may consist of unarmoured vessels of moderate size, fair speed under steam, armed with a few tolerably heavy guns, and carrying full sail-power.

"The second class may be vessels of great speed under steam, unarmoured, carrying light batteries and as great spread of canvas as can readily be given them ; very much such vessels as the Wampanoag class of our own navy were intended to be—calculated expressly to destroy the commerce of an enemy.

"The third class may consist of ships carrying the heaviest possible armour and armament, with strongly-built bows, the most powerful machinery that can be given them, of large coal-carrying capacity, and unencumbered by sails, everything being made secondary to the one object of obtaining victory in contending with the most powerful of possible opponents. Such vessels could never go to sea singly, but would cruise in couples or in squadrons. It seems hardly doubtful that attempts to combine the qualities of all classes in a single vessel, as has hitherto been

---

[1] *Journal Franklin Institute*, 1870. H. B. M. S. Monarch.

[2] London *Engineering*, 1875.

done, will be necessarily given up, although the classification indicated will certainly tend largely to restrict naval operations."

The introduction of the stationary, the floating, and the automatic classes of torpedoes, and of torpedo-vessels, has now become accomplished, and this element, which it was predicted by Bushnell and by Fulton three-quarters of a century ago would at some future time become important in warfare, is now well recognized by all nations. How far it may modify future naval establishments cannot be yet confidently stated, but it seems sufficiently evident that the attack, by any navy, of stationary defenses protected by torpedoes is now quite a thing of the past. It may be perhaps looked upon as exceedingly probable that torpedo-ships of very high speed will yet drive all heavily-armoured vessels from the ocean, thus completing the historic parallel between the man-in-armour of the middle ages and the armoured man-of-war of our own time.[1]

Of these classes, the third is of most interest, as exhibiting most perfectly the importance and variety of the work which the steam-engine is made to perform. On the later of these vessels, the anchor is raised by a steam anchor-hoisting apparatus; the heavier spars and sails are handled by the aid of a steam-windlass; the helm is controlled by a steering-engine, and the helmsman, with his little finger, sets in motion a steam-engine, which adjusts the rudder with a power which is unimpeded by wind or sea, and with an exactness that could not be exceeded by the hand-steering gear of a yacht; the guns are loaded by steam, are elevated or depressed, and are given lateral training, by the same power; the turrets in which the guns are incased are turned, and the guns are whirled toward every point of the compass, in less time than is required to sponge and reload

---

[1] *Vide* "Report on Machinery and Manufactures, etc., at Vienna," by the author, Washington, 1875.

them; and the ship itself is driven through the water by the power of ten thousand horses, at a speed which is only excelled on land by that of the railroad-train.

The British Minotaur was one of the earlier iron-clads. The great length and consequent difficulty of manœuvring, the defect of speed, and the weakness of armour of these vessels have led to the substitution of far more effective designs in later constructions. The Minotaur is a four-masted screw iron-clad, 400 feet long, of 59 feet beam and 26½ feet draught of water. Her speed at sea is about 12½ knots, and her engines develop, as a maximum, nearly 6,000 indicated horse-power. Her heaviest armour-plates are but 6 inches in thickness. Her extreme length and her unbalanced rudder make it difficult to turn rapidly. With *eighteen men at the steering-wheel* and sixty others on the tackle, the ship, on one occasion, was 7½ minutes in turning completely around. These long iron-clads were succeeded by the shorter vessels designed by Mr. E. J. Reed, of which the first, the Bellerophon, was of 4,246 tons burden, 300 feet long by 56 feet beam, and 24½ feet draught, of the 14-knot speed, with 4,600 horse-power; and having the "balanced rudder" used many years earlier in the United States by Robert L. Stevens,[1] it can turn in four minutes with eight men at the wheel. The cost of construction was some $600,000 less than that of the Minotaur. A still later vessel, the Monarch, was constructed on a system quite similar to that known in the United States as the Monitor type, or as a turreted iron-clad. This vessel is 330 feet long, 57½ feet wide, and 36 feet deep, drawing 24½ feet of water. The total weight of ship and contents is over 8,000 tons, and the engines are of over 8,500 horse-power. The armour is 6 and 7 inches thick on the hull, and 8 inches on the two turrets, over a heavy teak backing. The turrets contain each two 12-inch rifled guns, weighing 25 tons each, and,

---

[1] Still in use on the Hoboken ferry-boats.

with a charge of 70 pounds of powder, throwing a shot of 600 pounds weight with a velocity of 1,200 feet per second, and giving it a *vis viva* equivalent to the raising of over 6,100 tons one foot high, and equal to the work of penetrating an iron plate 13¼ inches thick. This immense vessel is driven by a pair of "single-cylinder" engines having steam-cylinders *ten feet* in diameter and of 4½ feet stroke of piston, driving a two-bladed Griffith screw of 23½ feet diameter and 26½ feet pitch, 65 revolutions, at the maximum speed of 14.9 knots, or about 17¼ miles, an hour. To drive these powerful engines, boilers having an aggregate of about 25,000 square feet (or more than a half-acre) of heating-surface are required, with 900 square feet of grate-surface. The refrigerating surface in the condensers has an area of 16,500 square feet—over one-third of an acre. The cost of these engines and boilers was £66,500.

Were all this vast steam-power developed, giving the vessel a speed of 15 knots, the ship, if used as a "ram," would strike an enemy at rest with the tremendous "energy" of 48,000 foot-tons—equal to the shock of the projectiles of eight or nine such guns as are carried by the iron-clad itself, simultaneously discharged upon one spot.

But even this great vessel is less formidable than later vessels. One of the latter, the Inflexible, is a shorter but wider and deeper ship than the Monarch, measuring 320 feet long, 75 feet beam, and 25 draught, displacing over 10,000 tons. The great rifles carried by this vessel weigh 81 tons each, throwing shot weighing a half-ton from behind iron-plating two feet in thickness. The steam-engines are of about the same power as those of the Monarch, and give this enormous hull a speed of 14 knots an hour.

The navy of the United States does not to-day possess iron-clads of power even approximating that of either of several classes of British and other foreign naval vessels.

The largest vessel of any class yet constructed is the Great Eastern (Fig. 146), begun in 1854 and completed in

1859, by J. Scott Russell, on the Thames, England. This ship is 680 feet long, 83 feet wide, 58 feet deep, 28 feet draught, and of 24,000 tons measurement. There are four paddle and four screw engines, the former having steam-cylinders 74 inches in diameter, with 14 feet stroke, the latter 84 inches in diameter and 4 feet stroke. They are collectively of 10,000 actual horse-power. The paddle-wheels are 56 feet in diameter, the screw 24 feet. The steam-boilers supplying the paddle-engines have 44,000 square feet (more than an acre) of heating-surface. The boilers supplying the screw-engines are still larger. At 30 feet draught, this great vessel displaces 27,000 tons. The engines were designed to develop 10,000 horse-power, driving the ship at the rate of 16½ statute miles an hour.

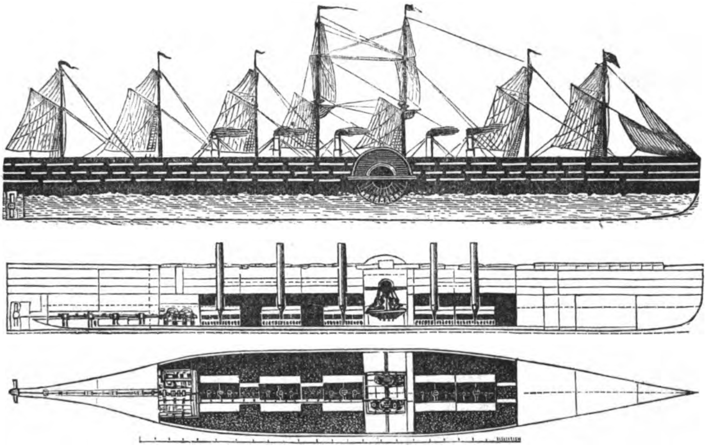


FIG. 146.—The Great Eastern.

The figures quoted in the descriptions of these great steamships do not enable the non-professional reader to form a conception of the wonderful power which is concentrated within so small a space as is occupied by their steam-machinery. The "horse-power" of the engines is that deter-power the work now done for the world by steam. The cost of the greater power is but about one-tenth that of horse-power, and by its means tasks are accomplished with ease which are absolutely impossible of accomplishment by animal power.

It is estimated that the total steam-power of the world is about 15,000,000 horse-power, and that, were horses actually employed to do the work which these engines would be capable of doing were they kept constantly in operation, the number required would exceed 60,000,000.

Thus, from the small beginnings of the Comte d'Auxiron and the Marquis de Jouffroy in France, of Symmington in Great Britain, and of Henry, Rumsey, and Fitch, and of Fulton and Stevens, in the United States, steam-navigation has grown into a great and inestimable aid and blessing to mankind.

We to-day cross the ocean with less risk, and transport ourselves and our goods at as little cost in either time or money as, at the beginning of the century, our parents experienced in traveling one-tenth the distance.

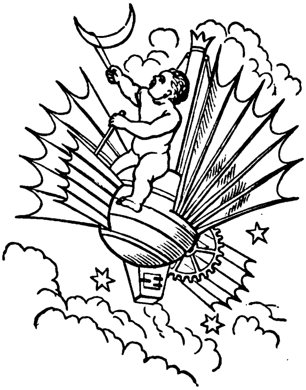
It is largely in consequence of this ingenious application of a power that reminds one of the fabled genii of Eastern romance, that the mechanic and the labourer of to-day enjoy comforts and luxuries that were denied to wealth, and to royalty itself, a century ago.

The magnitude of our modern steamships excites the wonder and admiration of even the people of our own time; and there is certainly no creation of art that can be grander in appearance than a transatlantic steamer a hundred and fifty yards in length, and weighing, with her stores, five or six thousand tons, as she starts on her voyage, moved by engines equal in power to the united strength of thousands of horses; none can more fully awaken a feeling of awe than an immense structure like the great modern iron-clads (Fig. 145), vessels having a total weight of 8,000 to 10,000 tons, and propelled by steam-engines of as many horse-power, carrying guns whose shot penetrate solid iron 20 inches thick, and having a power of impact, when steaming at moderate speed, sufficient to raise 35,000 tons a foot high.

Far more huge than the Monarch among the iron-clads even is that prematurely-built monster, the Great Eastern (Fig. 147), already described, an eighth of a mile long, and with steam doing the work of a stud of 45,000 horses.

Thus we are to-day witnessing the literal fulfillment of the predictions of Oliver Evans and of John Stevens, and almost that contained in the couplets written by the poet Darwin, who, more than a century ago, before even the earliest of Watt's improvements had become generally known, sang:

> "Soon shall thy arm, unconquered Steam, afar
> Drag the slow barge, or drive the rapid car;
> Or, on wide-waving wings expanded, bear
> The flying chariot through the fields of air."



CHAPTER VII.

THE PHILOSOPHY OF THE STEAM-ENGINE.

THE HISTORY OF ITS GROWTH; ENERGETICS AND THERMO-DYNAMICS.

> "OF all the features which characterize this progressive economical movement of civilized nations, that which first excites attention, through its intimate connection with the phenomena of production, is the perpetual and, so far as human foresight can extend, the unlimited growth of man's power over Nature. Our knowledge of the properties and laws of physical objects shows no sign of approaching its ultimate boundaries; it is advancing more rapidly, and in a greater number of directions at once, than in any previous age or generation, and affording such frequent glimpses of unexplored fields beyond as to justify the belief that our acquaintance with Nature is still almost in its infancy."—MILL.

THE growth of the philosophy of the steam-engine presents as interesting a study as that of the successive changes which have occurred in its mechanism.

In the operation of the steam-engine we find illustrated many of the most important principles and facts which constitute the physical sciences. The steam-engine is an exceedingly ingenious, but, unfortunately, still very imperfect, machine for transforming the heat-energy obtained by the chemical combination of a combustible with the supporter of combustion into mechanical energy. But the original source of all this energy is found far back of its first appearance in the steam-boiler. It had its origin at the beginning, when all Nature came into existence. After the solar system had been formed from the nebulous chaos of creation, the glowing mass which is now called the sun was the depository of a vast store of heat-energy, which was thence radiated into space and showered upon the attendant worlds in inconceivable quantity and with unmeasured intensity. During the past life of the globe, the heat-energy received from the sun upon the earth's surface was partly expended in the production of great forests, and the storage, in the trunks, branches, and leaves of the trees of which they were composed, of an immense quantity of carbon, which had previously existed in the atmosphere, combined with oxygen, as carbonic acid. The great geological changes which buried these forests under superincumbent strata of rock and earth resulted in the formation of coal-beds, and the storage, during many succeeding ages, of a vast amount of carbon, of which the affinity for oxygen remained unsatisfied until finally uncovered by the hand of man. Thus we owe to the heat and light of the sun, as was pointed out by George Stephenson, the incalculable store of potential energy upon which the human race is so dependent for life and all its necessaries, comforts, and luxuries.

This coal, thrown upon the grate in the steam-boiler, takes fire, and, uniting again with the oxygen, sets free heat in precisely the same quantity that it was received from the sun and appropriated during the growth of the tree. The actual energy thus rendered available is transferred, by conduction and radiation, to the water in the steam-boiler, converts it into steam, and its mechanical effect is seen in the expansion of the liquid into vapour against the superincumbent pressure. Transferred from the boiler to the engine, the steam is there permitted to expand doing work, and the heat-energy with which it is charged becomes partly converted into mechanical energy, and is applied to useful work in the mill or to driving the locomotive or the steamboat.

Thus we may trace the store of energy received from the sun and contained in our coal through its several changes until it is finally set at work; and we might go still fur-

When Hero lived at Alexandria, the great "Museum" was a most important centre, about which gathered the teachers of all then known philosophies and of all the then recognized but unformed sciences, as well as of all those technical branches of study which had already been so far developed as to be capable of being systematically taught. Astronomical observations had been made regularly and uninterruptedly by the Chaldean astrologers for two thousand years, and records extending back many centuries had been secured at Babylon by Calisthenes and given to Aristotle, the father of our modern scientific method. Ptolemy had found ready to his hand the records of Chaldean observers of eclipses extending back nearly 650 years, and marvelously accurate.[1]

A rude method of printing with an engraved roller on plastic clay, afterward baked, thus making up ceramic libraries, was practised long previous to this time; and in the alcoves in which Hero worked were many of these books of clay.

This great Library and Museum of Alexandria was founded three centuries before the birth of Christ, by Ptolemy Soter, who established as his capital that great Egyptian city when the death of his brother, the youthful but famous conqueror whose name he gave it, placed him upon the throne of the colossal successor of the then fallen Persian Empire. The city itself, embellished with every ornament and provided with every luxury that the wealth of a conquered world or the skill, taste, and ingenuity of the Greek painters, sculptors, architects, and engineers could provide, was full of wonders; it was a wonder in itself. This rich, populous, and magnificent city was the metropolis of the then civilized world. Trade, commerce, manufactures, and the fine arts were all represented in this

---

[1] Their estimate of the length of the Saros, or cycle of eclipses—over 19 years—was "within 19½ minutes of the truth."—DRAPER.

splendid exchange, and learning found its most acceptable home and noblest field within the walls of Ptolemy's Museum; its disciples found themselves welcomed and protected by its founder and his successors, Philadelphus and the later Ptolemies.

The Alexandrian Museum was founded with the declared object of collecting all written works of authority, of promoting the study of literature and art, and of stimulating and assisting experimental and mathematical scientific investigation and research. The founders of modern libraries, colleges, and technical schools have their prototype in intelligence, public spirit, and liberality, in the first of the Ptolemies, who not only spent an immense sum in establishing this great institution, but spared no expense in sustaining it. Agents were sent out into all parts of the world, purchasing books. A large staff of scribes was maintained at the museum, whose duty it was to multiply copies of valuable works, and to copy for the library such works as could not be purchased.

The faculty of the museum was as carefully organized as was the plan of its administration. The four principal faculties of astronomy, literature, mathematics, and medicine were subdivided into sections devoted to the several branches of each department. The collections of the museum were as complete as the teachers of the undeveloped sciences of the time could make them. Lectures were given in all branches of study, and the number of students was sometimes as great as twelve or thirteen thousand. The number of books which were collected here, when the barbarian leaders of the Roman troops under Cæsar burned the greater part of it, was stated to be 700,000. Of these, 400,000 were within the museum itself, and were all destroyed; the rest were in the temple of Serapis, and, for the time, escaped destruction.

The greatest of all the great men who lived at Alexandria at the time of the establishment of the museum was

Aristotle, the teacher of Alexander and the friend of Ptolemy. It is to Aristotle that we owe the systematization of the philosophical ideas of Plato and the creation of the inductive method, in which has originated all modern science. It is to the learned men of Alexandria that we are indebted for so effective an application of the Aristotelian philosophy that all the then known sciences were given form, and were so thoroughly established that the work of modern science has been purely one of development.

The inductive method, which built up all the older sciences, and which has created all those of recent development, consists, first, in the discovery and quantitative determination of facts ; secondly, when a sufficient number of facts have been thus observed and defined, in the grouping of those facts, and the detection, by a study of their mutual relations, of the natural laws which give rise to or regulate them. This simple method is that—and the only—method by which science advances. By this method, and by it only, do we acquire connected and systematic knowledge of all the phenomena of Nature of which the physical sciences are cognizant. It is only by the application of this Aristotelian method and philosophy that we can hope to acquire exact scientific knowledge of existing phenomena, or to become able to anticipate the phenomena which are to distinguish the future. The Aristotelian method of observing facts, and of inductive reasoning with those facts as a basis, has taught the chemist the properties of the known elementary substances and their characteristic behaviour under ascertained conditions, and has taught him the laws of combination and the effects of their union, enabling him to predict the changes and the phenomena, chemical and physical, which inevitably follow their contact under any specified set of conditions.

It is this process which has enabled the physicist to ascertain the methods of molecular motion which give us light, heat, or electricity, and the range of action and the and the wonderful and beautiful phenomena which—but a thousand years later—were afterward grouped into a science and called chemistry, were especially attractive to the Arabian scholars, and technical applications of discovered facts and laws assisted in a wonderfully rapid development of arts and manufactures.

When, a thousand years after Christ, the centre of intellectual activity and of material civilization had drifted westward into Andalusia, the foundation of every modern physical science except that now just taking shape—the all-grasping science of energetics—had been laid with experimentally derived facts; and in mathematics there had been erected a symmetrical and elegant superstructure. Even that underlying principle of all the sciences, the principle of the persistence of energy, had been, perhaps unwittingly, enunciated.

Distinguished historians have shown how the progress of civilization in Europe resulted in the creation, during the middle ages, of the now great middle class, which, holding the control of political power, governs every civilized nation, and has come into power so gradually that it was only after centuries that its influence was seen and felt. This, which Buckle[1] calls the intellectual class, first became active, independently of the military and of the clergy, in the fourteenth century. In the two succeeding centuries this class gained power and influence; and in the seventeenth century we find a magnificent advance in all branches of science, literature, and art, marking the complete emancipation of the intellect from the artificial conditions which had so long repressed its every effort at advancement.

Another great social revolution thus occurred, following another period of centuries of intellectual stagnation. The Saracen invaders were driven from Europe; the Crusaders invaded Palestine, in the vain effort to recover from the hands of the infidels the Holy Sepulchre and the Holy

---

[1] "History of Civilization in England," vol. i., p. 208. London, 1868.

tion which it was afterward given among the sciences; and the grand work of collating facts already ascertained, and of definitely stating principles which had previously been vaguely recognized, was splendidly done by Newton. The needs of physical astronomy urged this work upon him.

Da Vinci had, in the latter half of the fifteenth century, summarized as much of the statics of mechanical philosophy as had, up to his time, been given shape; he also rewrote and added very much to what was known on the subject of friction, and enunciated its laws. He had evidently a good idea of the principle of "virtual velocities," that simple case of equivalence of work, in a connected system, which has done such excellent service since; and with his mechanical philosophy this versatile engineer and artist curiously mingled much of physical science. Then Stevinus, the "brave engineer of Bruges," a hundred years later (1586), alternating office and field work, somewhat after the manner of the engineer of to-day, wrote a treatise on mechanics, which showed the value of practical experience and judgment in even scientific work. And thus the path had been cleared for Newton.

Meantime, also, Kepler had hit upon the true relations of the distances of the planets and their periodic times, after spending half a generation in blindly groping for them, thus furnishing those great landmarks of fact in the mechanics of astronomy; and Galileo had enunciated the laws of motion. Thus the foundation of the science of dynamics, as distinguished from statics, was laid, and the beginning was made of that later science of energetics, of which the philosophy of the steam-engine is so largely constituted.

Hooke, Huyghens, and others, had already seen some of the principal consequences of these laws; but it remained for Newton to enunciate them with the precision of a true mathematician, and to base upon them a system of dynamical laws, which, complemented by his announcement of the existence of the force of gravitation, and his statement of its laws, *Dynamics*, or kinetics, which treats of simple motion as an effect of the action of forces.

Energetics, which treats of modifications of energy under the action of forces, and of its transformation from one mode of manifestation to another, and from one body to another.

Under the latter of these four divisions of mechanical philosophy is comprehended that latest of the minor sciences, of which the heat-engines, and especially the steam-engine, illustrate the most important applications—*Thermodynamics.* This science is simply a wider generalization of principles which, as we have seen, have been established one at a time, and by philosophers widely separated both geographically and historically, by both space and time, and which have been slowly aggregated to form one after another of the sciences, and out of which, as we now are beginning to see, we are slowly evolving wider generalizations, and thus tending toward a condition of scientific knowledge which renders more and more probable the truth of Cicero's declaration: "One eternal and immutable law embraces all things and all times." At the basis of the whole science of energetics lies a principle which was enunciated before Science had a birthplace or a name:

All that exists, whether matter or force, and in whatever form, is indestructible, except by the Infinite Power which has created it.

That matter is indestructible by finite power became admitted as soon as the chemists, led by their great teacher Lavoisier, began to apply the balance, and were thus able to show that in all chemical change there occurs only a modification of form or of combination of elements, and no loss of matter ever takes place. The "persistence" of energy was a later discovery, consequent largely upon the experimental determination of the convertibility of heat-energy into other forms and into mechanical work, for which we are indebted to Rumford and Davy, and to the

This paper is of very great historical interest, as the now accepted doctrine of the persistence of energy is a generalization which arose out of a series of investigations, the most important of which are those which resulted in the determination of the existence of a definite quantivalent relation between these two forms of energy and a measurement of its value, now known as the "mechanical equivalent of heat." His experiment consisted in the determination of the quantity of heat produced by the boring of a cannon at the arsenal at Munich.

Rumford, after showing that this heat could not have been derived from any of the surrounding objects, or by compression of the materials employed or acted upon, says: "It appears to me extremely difficult, if not impossible, to form any distinct idea of anything capable of being excited and communicated in the manner that heat was excited and communicated in these experiments, except it be motion."[1] He then goes on to urge a zealous and persistent investigation of the laws which govern this motion. He estimates the heat produced by a power which he states could easily be exerted by one horse, and makes it equal to the "combustion of nine wax candles, each three-quarters of an inch in diameter," and equivalent to the elevation of "25.68 pounds of ice-cold water" to the boiling-point, or 4,784.4 heat-units.[2] The time was stated at "150 minutes." Taking the actual power of Rumford's Bavarian "one horse" as the most probable figure, 25,000 pounds raised one foot high per minute,[3] this gives the "mechanical equivalent"

---

[1] This idea was not by any means original with Rumford. Bacon seems to have had the same idea; and Locke says, explicitly enough: "Heat is a very brisk agitation of the insensible parts of the object . . . . so that what in our sensation is heat, in the object is nothing but motion."

[2] The British heat-unit is the quantity of heat required to heat one pound of water 1° Fahr. from the temperature of maximum density.

[3] Rankine gives 25,920 foot-pounds per minute—or 432 per second—for the average draught-horse in Great Britain, which is probably too high

of the foot-pound as 783.8 heat-units, differing but 1.5 per cent. from the now accepted value.

Had Rumford been able to eliminate all losses of heat by evaporation, radiation, and conduction, to which losses he refers, and to measure the power exerted with accuracy, the approximation would have been still closer. Rumford thus made the experimental discovery of the real nature of heat, proving it to be a form of energy, and, publishing the fact a half-century before the now standard determinations were made, gave us a very close approximation to the value of the heat-equivalent. Rumford also observed that the heat generated was "exactly proportional to the force with which the two surfaces are pressed together, and to the rapidity of the friction," which is a simple statement of equivalence between the quantity of work done, or energy expended, and the quantity of heat produced. This was the first great step toward the formation of a Science of Thermo-dynamics. Rumford's work was the corner-stone of the science.

Sir Humphry Davy, a little later (1799), published the details of an experiment which conclusively confirmed these deductions from Rumford's work. He rubbed two pieces of ice together, and found that they were melted by the friction so produced. He thereupon concluded: "It is evident that ice by friction is converted into water. . . . Friction, consequently, does not diminish the capacity of bodies for heat."

Bacon and Newton, and Hooke and Boyle, seem to have anticipated—long before Rumford's time—all later philosophers, in admitting the probable correctness of that modern dynamical, or vibratory, theory of heat which considers it a mode of motion; but Davy, in 1812, for the first

---

for Bavaria. The engineer's "horse-power"—33,000 foot-pounds per minute—is far in excess of the average power of even a good draught-horse, which latter is sometimes taken as two-thirds the former.

time, stated plainly and precisely the real nature of heat, saying: "The immediate cause of the phenomenon of heat, then, is motion, and the laws of its communication are precisely the same as the laws of the communication of motion." The basis of this opinion was the same that had previously been noted by Rumford.

So much having been determined, it became at once evident that the determination of the exact value of the mechanical equivalent of heat was simply a matter of experiment; and during the succeeding generation this determination was made, with greater or less exactness, by several distinguished men. It was also equally evident that the laws governing the new science of thermo-dynamics could be mathematically expressed.

Fourier had, before the date last given, applied mathematical analysis in the solution of problems relating to the transfer of heat without transformation, and his "Théorie de la Chaleur" contained an exceedingly beautiful treatment of the subject. Sadi Carnot, twelve years later (1824), published his "Réflexions sur la Puissance Motrice du Feu," in which he made a first attempt to express the principles involved in the application of heat to the production of mechanical effect. Starting with the axiom that a body which, having passed through a series of conditions modifying its temperature, is returned to "its primitive physical state as to density, temperature, and molecular constitution," must contain the same quantity of heat which it had contained originally, he shows that the efficiency of heat-engines is to be determined by carrying the working fluid through a complete cycle, beginning and ending with the same set of conditions. Carnot was not a believer in the vibratory theory of heat, and consequently was led into some errors; but, as will be seen hereafter, the idea just expressed is one of the most important details of a theory of the steam-engine.

Seguin, who has already been mentioned as one of the zero of heat-motion. But the one will have absorbed but $6\frac{3}{4}$ British thermal units, while the other will have absorbed $9\frac{1}{2}$. In the first case, all of this heat will have been employed in simply increasing the temperature of the air; in the second case, the temperature of the air will have been equally increased, and, besides, a certain amount of work—2,116.3 foot-pounds—must have been done in overcoming the resistance of the air; it is to this latter action that we must debit the additional heat which has disappeared. Now, $\frac{2,116.3}{2\frac{3}{4}} = 770$ foot-pounds per heat-unit—almost precisely the value derived from Joule's experiments. Had Mayer's measurement been absolutely accurate, the result of his calculation would have been an exact determination of the heat-equivalent, provided no heat is, in this case, lost by internal work.

Joule's most probably accurate measure was obtained by the use of a paddle-wheel revolving in water or other fluid. A copper vessel contained a carefully weighed portion of the fluid, and at the bottom was a step, on which stood a vertical spindle carrying the paddle-wheel. This wheel was turned by cords passing over nicely-balanced grooved wheels, the axles of which were carried on friction-rollers. Weights hung at the ends of these cords were the moving forces. Falling to the ground, they exerted an easily and accurately determinable amount of work, $W \times H$, which turned the paddle-wheel a definite number of revolutions, warming the water by the production of an amount of heat exactly equivalent to the amount of work done. After the weight had been raised and this operation repeated a sufficient number of times, the quantity of heat communicated to the water was carefully determined and compared with the amount of work expended in its development. Joule also used a pair of disks of iron rubbing against each other in a vessel of mercury, and measured the heat thus developed by friction, comparing it with the work done. The average of forty experiments with water gave the equivalent 772.692 foot-pounds; fifty with mercury gave 774.083; twenty with cast-iron gave 774.987—the temperature of the apparatus being from 55° to 60° Fahr.

Joule also determined, by experiment, the fact that the expansion of air or other gas without doing work produces no change of temperature, which fact is predicable from the now known principles of thermo-dynamics. He stated the results of his researches relating to the mechanical equivalent of heat as follows:

1. The heat produced by the friction of bodies, whether solid or liquid, is always proportional to the quantity of work expended.

2. The quantity required to increase the temperature of a pound of water (weighed *in vacuo* at 55° to 60° Fahr.) by one degree requires for its production the expenditure of a force measured by the fall of 772 pounds from a height of one foot. This quantity is now generally called "Joule's equivalent."

During this series of experiments, Joule also deduced the position of the "absolute zero," the point at which heat-motion ceases, and stated it to be about 480° Fahr. below the freezing-point of water, which is not very far from the probably true value, −493.2° Fahr. (273° C.), as deduced afterward from more precise data.

The result of these, and of the later experiments of Hirn and others, has been the admission of the following principle:

Heat-energy and mechanical energy are mutually convertible and have a definite equivalence, the British thermal unit being equivalent to 772 foot-pounds of work, and the metric *calorie* to 423.55, or, as usually taken, 424 kilogram-metres. The exact measure is not fully determined, however.

It has now become generally admitted that all forms of energy due to physical forces are mutually convertible with a definite quantivalence; and it is not yet determined that even vital and mental energy do not fall within the same great generalization. This quantivalence is the sole basis of the science of energetics.

The study of this science has been, up to the present time, principally confined to that portion which comprehends the relations of heat and mechanical energy. In the study of this department of the science, thermo-dynamics, Rankine, Clausius, Thompson, Hirn, and others have acquired great distinction. In the investigations which have been made by these authorities, the methods of transfer of heat and of modification of physical state in gases and vapours, when a change occurs in the form of the energy considered, have been the subjects of especial study.

According to the law of Boyle and Marriotte, the expansion of such fluids follows a law expressed graphically by the hyperbola, and algebraically by the expression $PV^x = A$, in which, with unchanging temperature, x is equal to 1. One of the first and most evident deductions from the principles of the equivalence of the several forms of energy is that the value of x must increase as the energy expended in expansion increases. This change is very marked with a vapour like steam—which, expanded without doing work, has an exponent less than unity, and which, when doing work by expanding behind a piston, partially condenses, the value of x increases to, in the case of steam, 1.111 according to Rankine, or, probably more correctly, to 1.135 or more, according to Zeuner and Grashof. This fact has an important bearing upon the theory of the steam-engine, and we are indebted to Rankine for the first complete treatise on that theory as thus modified.

Prof. Rankine began his investigations as early as 1849, at which time he proposed his theory of the molecular constitution of matter, now well known as the theory of molecular vortices. He supposes a system of whirling rings or adapted Carnot's principle to the new theory, and showed that his idea of the reversible engine and of the performance of a cycle in testing the changes produced still held good, notwithstanding Carnot's ignorance of the true nature of heat. Clausius also gave us the extremely important principle : It is impossible for a self-acting machine, unaided, to transfer heat from one body at a low temperature to another having a higher temperature.

Simultaneously with Rankine and Clausius, Prof. William Thomson was engaged in researches in thermo-dynamics (1850). He was the first to express the principle of Carnot as adapted to the modern theory by Clausius in the now generally quoted propositions :[1]

1. When equal mechanical effects are produced by purely thermal action, equal quantities of heat are produced or disappear by transformation of energy.
2. If, in any engine, a reversal effects complete inversion of all the physical and mechanical details of its operation, it is a perfect engine, and produces maximum effect with any given quantity of heat and with any fixed limits of range of temperature.

William Thomson and James Thompson showed, among the earliest of their deductions from these principles, the fact, afterward confirmed by experiment, that the melting-point of ice should be lowered by pressure 0.0135° Fahr. for each atmosphere, and that a body which contracts while being heated will always have its temperature decreased by sudden compression. Thomson applied the principles of energetics in extended investigations in the department of electricity, while Helmholtz carried some of the same methods into his favourite study of acoustics.

The application of now well-settled principles to the physics of gases led to many interesting and important de-

---

[1] *Vide* Tait's admirable "Sketch of Thermodynamics," second edition, Edinburgh, 1877.

shown that, at a certain point, which he calls the "critical point," the properties of the two states of the fluid fade into each other, and that, at that point, the two become continuous. With carbonic acid, this occurs at 75 atmospheres, about 1,125 pounds per square inch, a pressure which would counterbalance a column of mercury 60 yards, or nearly as many metres, high. The temperature at this point is about 90° Fahr., or 31° Cent. For ether, the temperature is 370° Fahr., and the pressure 38 atmospheres ; for alcohol, they are 498° Fahr., and 120 atmospheres ; and for bisulphide of carbon, 505° Fahr., and 67 atmospheres. For water, the pressure is too high to be determined ; but the temperature is about 775° Fahr., or 413° Cent.

Donny and Dufour have shown that these normal properties of vapours and liquids are subject to modification by certain conditions, as previously (1818) noted by Gay-Lussac, and have pointed out the bearing of this fact upon the safety of steam-boilers. It was discovered that the boiling-point of water could be elevated far above its ordinary temperature of ebullition by expedients which deprive the liquid of the air usually condensed within its mass, and which prevent contact with rough or metallic surfaces. By suspension in a mixture of oils which is of nearly the same density, Dufour raised drops of water under atmospheric pressure to a temperature of 356° Fahr.—180° Cent.—the temperature of steam of about 150 pounds per square inch. Prof. James Thompson has, on theoretical grounds, indicated that a somewhat similar action may enable vapour, under some conditions, to be cooled below the normal temperature of condensation, without liquefaction.

Fairbairn and Tate repeated the attempt to determine the volume and temperature of water at pressures extending beyond those in use in the steam-engine, and incomplete determinations have also been made by others.

Regnault is the standard authority on these data. His experiments (1847) were made at the expense of the French

Since Regnault's time, nothing of importance has been done in this direction. There still remains much work to be done in the extension of the research to higher pressures, and under conditions which obtain in the operation of the steam-engine. The volumes and densities of steam require further study, and the behaviour of steam in the engine is still but little known, otherwise than theoretically. Even the true value of Joule's equivalent is not undisputed.

Some of the most recent experimental work bearing directly upon the philosophy of the steam-engine is that of Hirn, whose determination of the value of the mechanical equivalent was less than two per cent. below that of Joule. Hirn tested by experiment, in 1853, and repeatedly up to 1876, the analytical work of Rankine, which led to the conclusion that steam doing work by expansion must become gradually liquefied. Constructing a glass steam-engine cylinder, he was enabled to see plainly the clouds of mist which were produced by the expansion of steam behind the piston, where Regnault's experiments prove that the steam should become drier and superheated, were no heat transformed into mechanical energy. As will be seen hereafter, this great discovery of Rankine is more important in its bearing upon the theory of the steam-engine than any made during the century. Hirn's confirmation stands, in value, beside the original discovery. In 1858 Hirn confirmed the work of Mayer and Joule by determining the work done and the carbonic acid produced, as well as the increased temperature due to their presence, where men were set at work in a treadmill; he found the elevation of temperature to be much greater in proportion to gas produced when the men were resting than when they were at work. He thus proved conclusively the conversion of heat-energy into mechanical work. It was from these experiments that Helmholtz deduced the "modulus of efficiency" of the human machine at one-fifth, and concluded that the heart works with eight times the efficiency of a locomotive-engine, thus the measure of the work which a body is capable of doing under certain conditions which, without expending energy, may be made to affect it, as by the breaking of a cord by which a weight is suspended, or by firing a mass of explosive material. The British measure of energy is the foot-pound; the metric measure is the kilogrammetre.

Energy, whether kinetic or potential, may be observable and due to mass-motion; or it may be invisible and due to molecular movements. The energy of a heavenly body or of a cannon-shot, and that of heat or of electrical action, are illustrations of the two classes. In Nature we find utilizable potential energy in fuel, in food, in any available head of water, and in available chemical affinities. We find kinetic energy in the motion of the winds and the flow of running water, in the heat-motion of the sun's rays, in heat-currents on the earth, and in many intermittent movements of bodies acted on by applied forces, natural or artificial. The potential energy of fuel and of food has already been seen to have been derived, at an earlier period, from the kinetic energy of the sun's rays, the fuel or the food being thus made a storehouse or reservoir of energy. It is also seen that the animal system is simply a "mechanism of transmission" for energy, and does not create but simply diverts it to any desired direction of application.

All the available forms of energy can be readily traced back to a common origin in the potential energy of a universe of nebulous substance (chaos), consisting of infinitely diffused matter of immeasurably slight density, whose "energy of position" had been, since the creation, gradually going through a process of transformation into the several forms of kinetic and potential energy above specified, through intermediate methods of action which are usually still in operation, such as the potential energy of chemical affinity, and the kinetic forms of energy seen in solar radiation, the rotation of the earth, and the heat of its interior.

The *measure* of any given quantity of energy, whatever ture into the variation of a "function," which function is the rate of variation of the work so done with temperature. This function is the quantity called by Rankine the "heat-potential" of the substance for the given kind of work. A similar function, which comprehends the total heat-variation, including both heat transformed and heat needed to effect accompanying physical changes, is called the "thermo-dynamic function." Rankine's expression for the general equation of thermo-dynamics includes the latter, and is given by him as follows:

$$J\,dh = dH = k\,d\tau + \tau\,dF = \tau\,d\phi,$$

in which J is Joule's equivalent, dh the variation of total heat in the substance, $k\,d\tau$ the product of the "dynamic specific heat" into the variation of temperature, or the total heat demanded to produce other changes than a transformation of energy, and $\tau\,dF$ is the work done by the transformation of heat-energy, or the product of the absolute temperature, τ, into the differential of the heat-potential. ϕ is the thermo-dynamic function, and $\tau\,d\phi$ measures the whole heat needed to produce, simultaneously, a certain amount of work or of mechanical energy, and, at the same time, to change the temperature of the working substance.

Studying the behaviour of gases and vapors, it is found that the work done when they are used, like steam, in heat-engines, consists of three parts:

(*a.*) The change effected in the total actual heat-motion of the fluid.

(*b.*) That heat which is expended in the production of internal work.

(*c.*) That heat which is expended in doing the external work of expansion.

In any case in which the total heat expended exceeds that due the production of work on external bodies, the excess so supplied is so much added to the intrinsic energy of the substance absorbing it.

CHAPTER VIII.

THE PHILOSOPHY OF THE STEAM-ENGINE.

ITS APPLICATION; ITS TEACHINGS RESPECTING THE CONSTRUCTION OF THE ENGINE AND ITS IMPROVEMENT.

"OFTENTIMES an Uncertaintie hindered our going on so merrily, but by persevering the Difficultie was mastered, and the new Triumph gave stronger Heart unto us."—RALEIGH.

"If everything which we cannot comprehend is to be called an impossibility, how many are daily presented to our eyes! and in contemning as false that which we consider to be impossible, may we not be depreciating a giant's effort to give an importance to our own weakness?"—MONTAIGNE.

"They who aim vigorously at perfection will come nearer to it than those whose laziness or despondency makes them give up its pursuit from the feeling of its being unattainable."—CHESTERFIELD.

As has been already stated, the steam-engine is a machine which is especially designed to transform energy, originally dormant or potential, into active and usefully available kinetic energy.

When, millions of years ago, in that early period which the geologists call the carboniferous, the kinetic energy of the sun's rays, and of the glowing interior of the earth, was expended in the decomposition of the vast volumes of carbonic acid with which air was then charged, and in the production of a life-sustaining atmosphere and of the immense forests which then covered the earth with their almost inconceivably luxuriant vegetation, there was stored up for the benefit of the human race, then uncreated, an inconceivably great treasure of potential energy, which we are now just beginning to utilize. This potential energy becomes kinetic and available wherever and whenever the powerful chemical affinity of oxygen for carbon is permitted to come into play; and the fossil fuel stored in our coal-beds or the wood of existing forests is, by the familiar process of combustion, permitted to return to the state of combination with oxygen in which it existed in the earliest geological periods.

The philosophy of the steam-engine, therefore, traces the changes which occur from this first step, by which, in the furnace of the steam-boiler, this potential energy which exists in the tendency of carbon and oxygen to combine to form carbonic acid is taken advantage of, and the utilizable kinetic energy of heat is produced in equivalent amount, to the final application of resulting mechanical energy to machinery of transmission, through which it is usefully applied to the elevation of water, to the driving of mills and machinery of all kinds, or to the hauling of "lightning" trains on our railways, or to the propulsion of the Great Eastern.

The kinetic heat-energy developed in the furnace of the steam-boiler is partly transmitted through the metallic walls which inclose the steam and water within the boiler, there to evaporate water, and to assume that form of energy which exists in steam confined under pressure, and is partly carried away into the atmosphere in the discharged gaseous products of combustion, serving, however, a useful purpose, *en route*, by producing the draught needed to keep up combustion.

The steam, with its store of heat-energy, passes through tortuous pipes and passages to the steam-cylinder of the engine, losing more or less heat on the way, and there expands, driving the piston before it, and losing heat by the duce the principles which govern its design and construction, guide us in its management, and determine its efficiency.

In the furnace of the boiler, the quantity of heat developed in available form is proportional to the amount of fuel burned. It is available in proportion to the temperature attained by the products of combustion; were this temperature no higher than that of the boiler, the heat would all pass off unutilized. But the temperature produced by a given quantity of heat, measured in heat-units, is greater as the volume of gas heated is less. It follows that, at this point, therefore, the fuel should be perfectly consumed with the least possible air-supply, and the least possible abstraction of heat before combustion is complete. High temperature of furnace, also, favours complete combustion. We hence conclude that, in the steam-boiler furnace, fuel should be burned completely in a chamber having non-conducting walls, and with the smallest air-supply compatible with thorough combustion; and, further, that the air should be free from moisture, that greatest of all absorbents of heat, and that the products of combustion should be removed from the furnace before beginning to drain their heat into the boiler. A fire-brick furnace, a large combustion-chamber with thorough intermixture of gases within it, good fuel, and a restricted and carefully-distributed supply of air, seem to be the conditions which meet these requisites best.

The heat generated by combustion traverses the walls which separate the gases of the furnace from the steam and water confined within the boiler, and is then taken up by those fluids, raising their temperature from that of the entering "feed-water" to that due the steam-pressure, and expanding the liquid into steam occupying a greatly-increased volume, thus doing a certain amount of work, besides increasing temperature. The extent to which heat may thus be usefully withdrawn from the furnace-gases depends upon the conductivity of the metallic wall, the rate at which the water will take heat from the metal, and the difference of temperature on the two sides of the metal. Extended "heating-surface," therefore, a metal of high conducting power, and a maximum difference of temperature on the two sides of the separating wall of metal, are the essential conditions of economy here. The heating-surface is sometimes made of so great an area that the temperature of the escaping gases is too low to give good chimney-draught, and a "mechanical draught" is resorted to, revolving "fan-blowers" being ordinarily used for its production. It is most economical to adopt this method. The steam-boiler is generally constructed of iron—sometimes, but rarely, of cast-iron, although "steel," where not hard enough to harden or temper, is better in consequence of its greater strength and homogeneousness of structure, and its better conductivity. The maximum conductivity of flow of heat for any given material is secured by so designing the boiler as to secure rapid, steady, and complete circulation of the water within it. The maximum rapidity of transfer throughout the whole area of heating-surface is secured, usually, by taking the feed-water into the boiler as nearly as possible at the point where the gases are discharged into the chimney-flue, withdrawing the steam nearer the point of maximum temperature of flues, and securing opposite directions of flow for the gases on the one side and the water on the other. Losses of heat from the boiler, by conduction and radiation to surrounding bodies, are checked as far as possible by non-conducting coverings.

The mechanical equivalent of the heat generated in the boiler is easily calculated when the conditions of working are known. A pound of pure carbon has been found to be capable of liberating by its perfect combustion, resulting in the formation of carbonic acid, 14,500 British thermal units, equivalent to $14,500 \times 772 = 11,194,000$ foot-pounds of work, and, if burned in one hour, to $\frac{11194000}{1980000} = 5.6$ horse-power. In other words, with perfect utilization, but $\frac{10}{56} = 0.177$, or available heat into mechanical work. The engines of the steamer Ericsson closely approached this figure, and gave a horse-power for each 1.87 pound of coal burned per hour.

Steam expands in the steam-cylinder quite differently under different circumstances. If no heat is either communicated to it or abstracted from it, however, it expands in an hyperbolic curve, losing its tension much more rapidly than when expanded without doing work, in consequence both of its change of volume and its condensation. The algebraic expression for this method of expansion is, according to Rankine, $PV^{1.111} = C$, a constant, or, according to other authorities, from $PV^{1.135} = C$ to $PV^{1.333} = C$. The greater the value of the exponent of V, the greater the efficiency of the fluid between any two temperatures. The maximum value has been found to be given where the steam is saturated, but perfectly dry, at the commencement of its expansion. The loss due to condensation on the cooled interior surface of the cylinder at the commencement of the stroke and the subsequent reëvaporation as expansion progresses is least when the cylinder is kept hot by its steam-jacket and when least time is given during the stroke for this transfer of heat between the metal and the vapour.

It may be said that, all things considered, therefore, losses of heat in the steam-cylinder are least when the steam enters dry, or moderately superheated, where the interior surfaces are kept hottest by the steam-jacket or by the hot-air jacket sometimes used, and where piston-speed and velocity of rotation are highest.[1] The best of compound engines, using steam of seventy-five pounds pressure and condensing, usually require about two pounds of coal per hour—20,000,000 foot-pounds of energy at the furnace—to develop a horse-power, i.e., about ten times the heat-equivalent of the mechanical work which they accom-

---

[1] In some cases, as in the Allen engine, the speed of piston has become very high, approaching 800 $\sqrt[3]{\text{stroke}}$.

vessel, while the power which had been obtained from it in the steam-cylinder was transmitted through still other parts, to the pumps, or wherever work was to be done.

Watt, also, took the initiative in another direction. He continually increased the efficiency of the machine by improving the proportions of its parts and the character of its workmanship, thus making it possible to render available many of those improvements in detail upon which effectiveness is so greatly dependent and which are only useful when made by a skillful workman.

Watt and his contemporaries also commenced that movement toward higher pressures of steam and greater expansion which has been the most striking feature noticed in the progress of steam-engineering since his time. Newcomen used steam of barely more than atmospheric pressure and raised 105,000 pounds of water one foot high with a pound of coal consumed. Smeaton raised the pressure somewhat and increased the duty considerably. Watt started with a duty double that of Newcomen and raised it to 320,000 foot-pounds per pound of coal, with steam at 10 pounds pressure. To-day, Cornish engines of the same general plan as those of Watt, but worked with 40 to 60 pounds of steam and expanding three or four times, do a duty probably averaging, with the better class of engines, 600,000 foot-pounds per pound of coal. The compound pumping-engine runs the figure up to about 1,000,000.

The increase in steam-pressure and in expansion since Watt's time has been accompanied by a very great improvement in workmanship—a consequence, very largely, of the rapid increase in perfection, and in the wide range of adaptation of machine-tools—by higher skill and intelligence in designing engines and boilers, by increased piston-speed, greater care in obtaining dry steam, and in keeping it dry until thrown out of the cylinder, either by steam-jacketing or by superheating, or both combined; it has further been accompanied by a greater attention to the imtion has, to some extent, followed the completion of the primary one, in which secondary process one operation is conducted partly in one and partly in another portion of the machine. This is illustrated by the two cylinders of the compound engine and by the duplication noticed in the binary engine.

Thirdly. The direction of improvement has been marked by a continual increase of steam-pressure, greater expansion, provision for obtaining dry steam, high piston-speed, careful protection against loss of heat by conduction or radiation, and, in marine engines, by surface condensation.

The direction which improvement seems now to be taking, and the proper direction, as indicated by an examination of the principles of science, as well as by our review of the steps already taken, would seem to be: working between the widest attainable limits of temperature.

Steam must enter the machine at the highest possible temperature, must be protected from waste, and must retain, at the moment before exhaust, the least possible amount of heat. He whose inventive genius, or mechanical skill, contributes to effect either the use of higher steam with safety and without waste, or the reduction of the temperature of discharge, confers a boon upon mankind.

In detail: In the engine, the tendency is, and may probably be expected to continue, in the near future at least, toward higher steam-pressure, greater expansion in more than one cylinder, steam-jacketing, superheating, a careful use of non-conducting protectors against waste, and the adoption of still higher piston-speeds.

In the boiler: more complete combustion without excess of air passing through the furnace, and more thorough absorption of heat from the furnace-gases. The latter will probably be ultimately effected by the use of a mechanically produced draught, in place of the far more wasteful method of obtaining it by the expenditure of heat in the chimney.

3. Proper connection with its work, that it may do its work under the conditions assumed in its design.

4. Skillful management by those in whose hands it is placed.

In general, it may be stated that, to secure maximum economical efficiency, steam should be worked at as high a pressure as possible, and the expansion should be fixed as nearly as possible at the point of maximum economy for that pressure.[1] It is even more disadvantageous to cut off too short than to "'follow' too far." With considerable expansion, steam-jacketing and moderate superheating should be adopted, to prevent excessive losses by internal condensation and reëvaporation; and expansion should take place in double cylinders, to avoid excessive weight of parts, irregularity of motion, and great loss by friction.

External surfaces should be carefully covered by non-conductors and non-radiators, to prevent losses by conduction and radiation of heat. It is especially necessary to reduce back-pressure and to obtain the most perfect vacuum possible without overloading the air-pump, if it is desired to obtain the maximum efficiency by expansion, and it then becomes also very necessary to reduce losses by "dead-spaces" and by badly-adjusted valves.

The piston-speed should be as great as can be sustained with safety.

The expansion-valve gear should be simple. The point of cut-off is perhaps best determined by the governor. The valve should close rapidly, but without shock, and should be balanced, or some other device should be adopted to make it easy to move and free from liability to cutting or rapid wear.

---

[1] In general, the number of times which the volume of steam may be expanded in the standard single-cylinder, high-pressure engine with maximum economy, is not far from $\frac{1}{2}\sqrt{P}$, where P is the pressure in pounds per square inch; it rarely exceeds $0.75\sqrt{P}$. This may be exceeded in double-cylinder engines.

opposite. The cold water should enter where the cooled gases leave, and the steam should be taken off farthest from that point. The temperature of chimney-gases has thus been reduced in practice to less than 300° Fahr., and an efficiency equal to 0.75 to 0.80 the theoretical has been attained.

The extent of heating-surface simply, in all of the best forms of boiler, determines the efficiency, and in them the disposition of that surface seldom affects it to any great extent. The area of heating-surface may also be varied within very wide limits without very greatly modifying efficiency. A ratio of 25 to 1 in flue and 30 to 1 in tubular boilers represents the relative area of heating and grate surfaces as chosen in the practice of the best-known builders.

The material of the boiler should be tough and ductile iron, or, better, a soft steel containing only sufficient carbon to insure melting in the crucible or on the hearth of the melting-furnace, and so little that no danger may exist of hardening and cracking under the action of sudden and great changes of temperature.

Where iron is used, it is necessary to select a somewhat hard, but homogeneous and tough, quality for the fire-box sheets or any part exposed to flames.

The factor of safety is invariably too low in this country, and is never too high in Europe. Foreign builders are more careful in this matter than our makers in the United States. The boiler should be built strong enough to bear a pressure at least six times the proposed working-pressure; as the boiler grows weak with age, it should be occasionally tested to a pressure far above the working-pressure, which latter should be reduced gradually to keep within the bounds of safety. In the United States, the factor of safety is seldom more than four in the new boilers, frequently much less, and even this is reduced practically to one and a third by the operation of our inspection-laws.

The principles just enunciated are those generally, perhaps universally, accepted principles which are stated in all text-books of science and of steam-engineering, and are accepted by both engineers and men of science.

These principles are correct, and the deductions which have been here formulated are rigidly exact, as applied to all types of heat-engine in use; and they lead us to the determination, in all cases, of the "modulus" of efficiency of the engine, i. e., to the calculation of the ratio of its actual efficiency to that efficiency which it would have, were it absolutely free from loss of heat by conduction or radiation, or other method of loss of heat or waste of power, by friction of parts or by shock.

The best modern marine compound engines sometimes, as we have seen, consume as little as two pounds of coal per horse-power and per hour; but this is but about one-tenth the power derivable from the fuel, were all its heat thoroughly utilized. This loss may be divided thus: 70 per cent. rejected in exhausted steam; 20 per cent. lost by conduction and radiation and by faults of mechanism and design; and only the 10 per cent. remaining is utilized. Thirty per cent. of the heat generated in the furnace is usually lost in the chimney, and of the remainder, which enters the engine, 20 per cent. at most is all which we can hope to save any portion of by improvements effected in our best existing type of steam-engine. It has already been shown how the engineer can best proceed in attempting this economy.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET