British Steam Locomotive Design

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BRITISH STEAM LOCOMOTIVE DESIGN.

A Thesis submitted to the faculty of History of Art and Design and Complimentary Studies in candidacy for B. Sc. Degree.

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May 1984.

ACKNOWLEDGEMENT.

I wish to express my gratitude to:-

Robert Guinness for allowing me to examine his collection of Locomotive Models.

William Garner for his help and guidance in the preparation of this Thesis.

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CONTENTS.

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INTRODUCTION.

The extent and influence which railways have had on the emergence of industrialized society, must be credited to the development of steam locomotives. Not alone did they provide the power of movement buth their appearance inspired acclaim and acceptance among the masses which was fundamental to the growth and success of the railways. From the earliest development steam power aroused the minds of experimenters and entreponours, and in its application the acclaim of all who saw it.

This thesis outlines the early experimentation with steam, and traces its development through stationary engines until the first motive engine in 1770. Chapter Twe examines the factors which were influential in the direction motive steam was to take. This culminated in the rainhill trials which was the launch of locomotives as a successful business venture .

The stationary steam engine had origonated the development of a new type of engine , which was used in locomotive building initially. The development of the locomotive required a much more precise form of machining and building which was developed for this purpose. This resulted in the first true machine product. Various improvements were made to the mechanical systems of the engines which increased the performance and influenced the evolvement of the engine form. These are outlined briefly under specific headings.

The Developments after the 1850's were concerned with improved performance and appearance which was sometimes lost amidst the increased tendancy towards mass production. Some of the more influencial or distinguished designs of the latter half of the Nineteenth Century are discussed. Some of the more important foreign influences are highlighted although it is appreciated that a greater interplay of ideas was now occuring. This seems to have been in the area of mechanical improvements rather than aestetic qualities. By the twentieth century, aestetic interplay was considerable, and was made apparent in British design. This resulted in a break away from conventional designs by individual engine builds. These designs are given preferance in discussion of the later stages of the steam age. This may not reflect their actual position within the overall strata of twentieth century engines. The influence of streamline is seen as the culmination of the form and performance on the British Locomotive. The search for further improvement and refinement was drastically ended with the outbreak of the second world war, from which it never recovered.

THE DEVELOPMENT OF STEAM TECHNOLOGY.

Steam technology of the modern era has its roots in the Seventeenth Century. Steam power was however known in the ancient world. During the later Roman Empire two engineers of the time,Ctsehius and Vitruvius seemed to possess remarkable knowledge of the properties of steam. They invented several devices including a door opener and a spinning sphere called an "Aeolipyle " (Fig 1). The "Aeolipyle" was powered by small jets of steam, and employs in its simplest form the principals of the reaction turbine. These devices were only regarded as amusing toys for the nobility and were never developed.

It was a desire to provide practical improvements to laborious tasks which eventually allowed the fullest use of steam to develop. There was never this desire during the Roman Empire, for it had a stagnant economic system, a political system which emphasised stability, and a social system dependant on slaves for menial tasks. Intellegent men regarded practical activities concerned with production to be unworthy of their attention. Innovation was just a hobby of the aristocracy.

In England in the Seventeenth Century circumstances were very different. The European Rennaissance had succeeded in changing mans attitude towards the world he lived in. A new world picture arose, concentrating mans powers upon scientific enquiry.

The first attempts to harness steampower in Rennaissance Europe followed on the classical lines closely, in that they were inspired to amuse. Giamballista della Porta (1536 - 1605) in Naples and Solomon de Caus (1576 - 1626) in England, simply used the pressure of steam to force water up a pipe. In della Porta's apparatus, steam was passed into an upper sealed tank, forcing water from the tank through a pipe. (Fig 2.) De Cause's merely consisted of a spherical copper cylinder from which, water could be expelled through a vertical pipe (Fig 3.) He used this idea to provide water fountains for the gardens of nobelity.

The Scientific Revolution which was concerned with experimental methods, and a practical way of increasing mans power over nature, blossomed in the first half of the Century. Established Authorities resented this revolution as some of the new ideas undermined their integrity. This has remained an important feature of modern science.

The exploration of steam power was made possible by three principal discoveries. Evangelista Torricelli (1608 - 1647) deduced that the earths atmosphere had weight. This he concluded after studying why a large pump, would only draw water up thirty two feet of a suction pipe. He proposed that the lighter the liquid, the further it would travel up the pipe, and equalise the pressure of the atmosphere.

The work of Otto Van Guericke (1602 - 1686) in creating a vacuum, was of major importance in the exploration of steam power. His belief that there was no air in outer space (because it would slow down the stars) led him to create a vacuum. He filled a closed vessel with water and pumped it out without allowing the atmosphere to penetrate it. The first vessel collapsed, but by using a sphere he succeeded, and after withdrawing a plug air rushed in. He demonstrated the force of a vacuum before Ferdinand III, where sixteen horses couldn't seperate two half spheres containing a vacuum.

Guericke's second experiment was of more significance. This was the construction of a cylinder with a tight fitting piston. He allowed twenty men to haul the piston to the open end, and after connecting an exhausted sphere, the piston was pulled with such a force that the men couldn't hold it. (Fig 4.).

These experiments had shown that the atmosphere was a source of power, but what was needed was a means of creating a vacuum. Some even turned to using gunpowder as a means of expelling air.

Denis Papin (1647 - 1712) a member of the Academie Royal des Sciences before going to England hit upon the idea of condensing steam to form a vacuum. His apparatus (Fig 5.) used a small amount of water in an enclosed vessel to give steam after heating. The piston was lifted by the steam and then held in position, when the steam had cooled the piston was released , raising a considerable weight in moving downwards. Thus Papin demonstrated in (1690 - 95) the principal of Newcome's atmospheric engine which he himself turned aside in favour of other means of utilizing steam power.

The first engine to haveany success was that of Thomas Savery, patented in 1698. It was a "New invention for raisening water and accasioning motion to all sorts of mill work by impelling force of fire". Savery called it the "Miners Friend" and this was appropriate as most early engines were used for pumping water from mines. (Fig 6.)

Savery was a prolific inventor and by 1699 he had designed an engine with twin boilers. This gave a continuous flow of water, as the steam supply was allowed altornatively to each boiler by stop cocks. These were controlled by manual valves initially, but he later connected them by "Wheelwork" to the engine.

The standard of workmanship had to be improved to enable these engines to be developed. The stop-cocks and pipework were made from brass, while the receivers and boilers were of beaten copper. The boilers were never fitted with safety values during this period and credit for this later invention belongs to Papin. These engines failed through their unreliability, and inability to raise water to any great height.

Thomas Newcomen (1663 - 1729) who described himself as an 'Ironmonger", and his assistant John Calley brought the 'Miners Friend' to a much more developed stage . Although he lost financial control over his engine he must be credited with its design. Contradictory opinions are voiced as to theinfluences on his design, principally because he was a provincial 'Ironmonger' .

What Newcomen did was to combine Guericke's Piston and Cylinder with Savery's boiler. He placed his boiler beneath the vertical cylinder, and connected its piston to the cross beam or "great lever" (Fig 7.). This advance was to have far reaching effects on the development of the industrial revolution in England.

It seems likely that for early experiments Newcomen used seven inch diameter brass cylinders as these were commonly used for pumps at the time. The inside could not be bored cylindrical by any machine at that time, so it would be laboriously fettled and lapped by hand. The piston was leather faced as in pump practice, but he used a water seal above the open end to overcome air penetration.

To condense the steam, he initially enclosed the cylinder with a lead jacket, through which he circulated cold water . This was a very slow process of cooling, and it was found by accident or trial and error, that injection of water into the cylinder gave rapid condensation.

The first working engine was at Wheal Vor in 1710 where it worked for only four years, because of the scarcity of fuel in Cornwall at the time. The most significant use of his engine was in the Midlands coalmines where fueling was not a problem. It was used to pump water from great depths in the shafts and truly became the miners friend.

The Newcomen engine was refined and improved, partly through the use of iron, which was cheap and strong. In Europe J.E. Fisher Van Erlach built an engine as early as 1722, and later introduced a method of counterbalancing the weight of the pump rods by a second balance beam. The engines built in 1732 were unique because the cylinder was offset from the boiler. (Fig 8.). These engines had cylinder diameters of 32½ inches by a foot long and lifted from a depth of 900ft at 8 strokes per minute.

James Watt (1736 - 1819) while trying to improve a Newcomen model in 1765 developed a seperate condenser. This allowed the cylinder to be kept permanently hot and the condeser permanently cold, which improved efficency, speed and safety enormously . In 1784 he introduced steam above and below the piston alternatively, controlling the process by an automatic sequence of value changes.

This was a much more advanced machine requiring more expertise in manufacturing. The valves and other moving parts were made at Watts and Matthew Boultons workshops in Soho Birmingham . This use of precision engineering techniques for the manufacture of large machines gave birth to the modern engineering industry. These skills had previously been used only in clockmaking and scientific instruments. The engines were used more for mining tin and copper in Cornwall, because of their high initial cost and low fuel consumption.

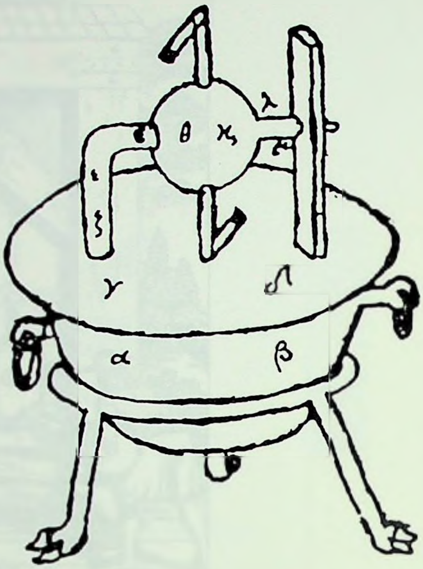
Until the 1780's the steam engine had been basically a pumping engine. The simple reciprocating action restricted their use. To achieve rotative action they were used to fill a reservoir with water, which turned a conventional water wheel.

Watt and his partner Boulton who was involved in the manufacture of fashionable objects developed a "sun and planet" gearing for rotative action (Fig 9) . A gear wheel was fixed to the end of the connecting rod "the planet" which moved round a similar wheel "the sun" on the driving shaft. Using a heavy fly wheel on the shaft, the engine produced a smooth rotative action.

He patented three major improvements to the engine in the next years. The "double action " piston to increase smoothness of rotation, the "parallel motion" to enable the piston rod to be kept vertical throughout its movements, and his adaption of the "centrifugal governor" to adjust the steam input to the engine.

The engines were introduced into the iron industry for blast furnaces and rolling mills. They were also used for corn grinding and most significantly for the cotton textile industry, which was previously powered by water wheels. The steam engine was a powerful agent in promoting the spread of the factory system.

The end of James Watts patent resulted in a burst of activity in those areas where he had most resisted innovation. These were high pressure steam and transport. Watt had experimented with expansive steam, but the boilers could not withstand more than four or five pounds per square inch.



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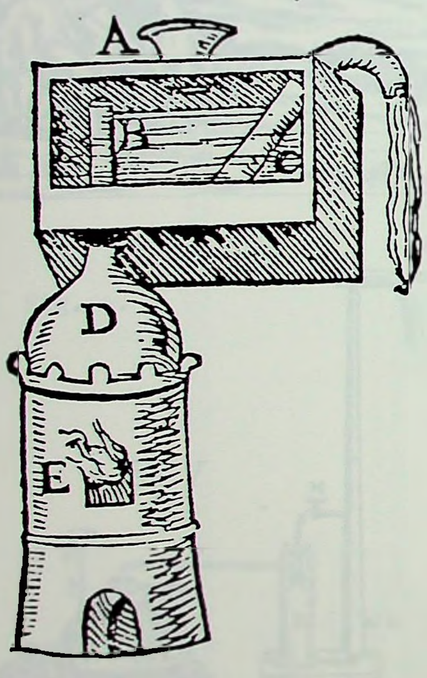

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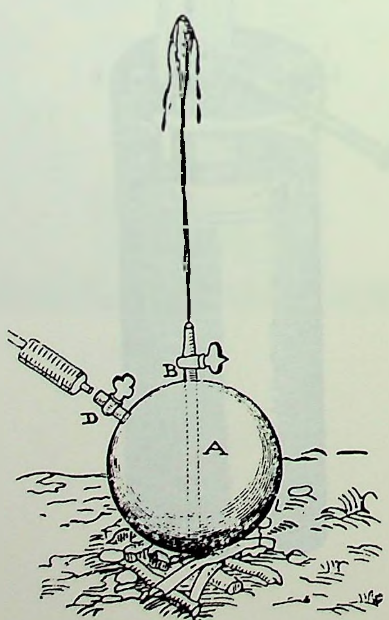

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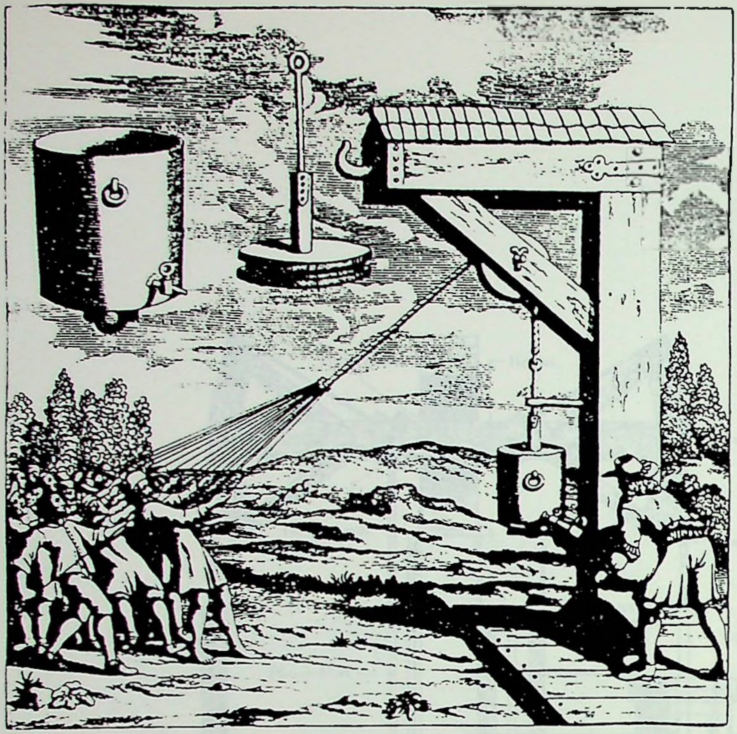

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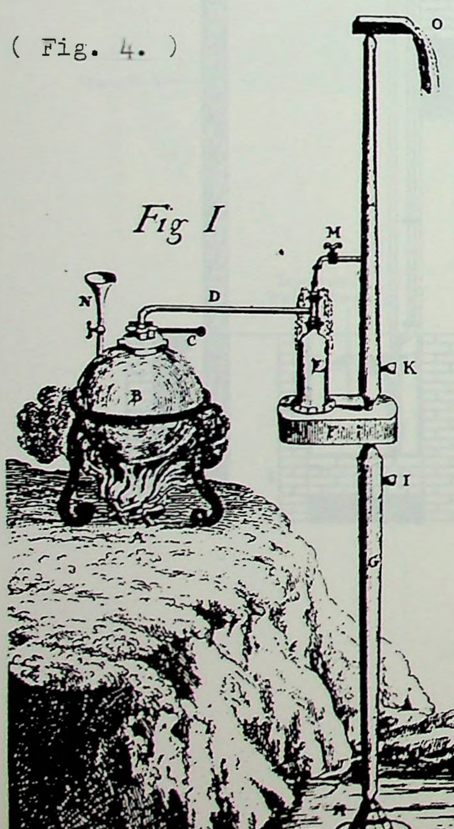

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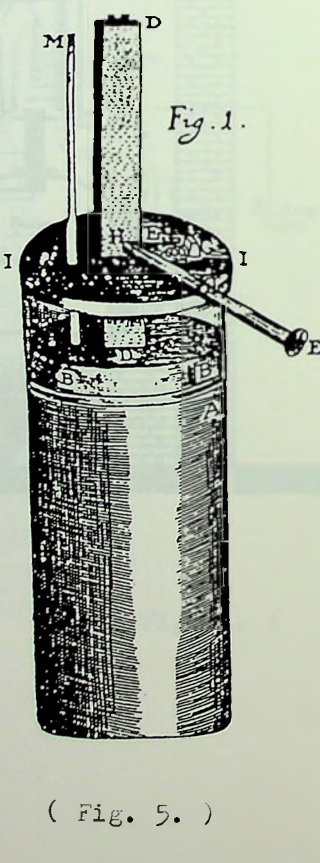

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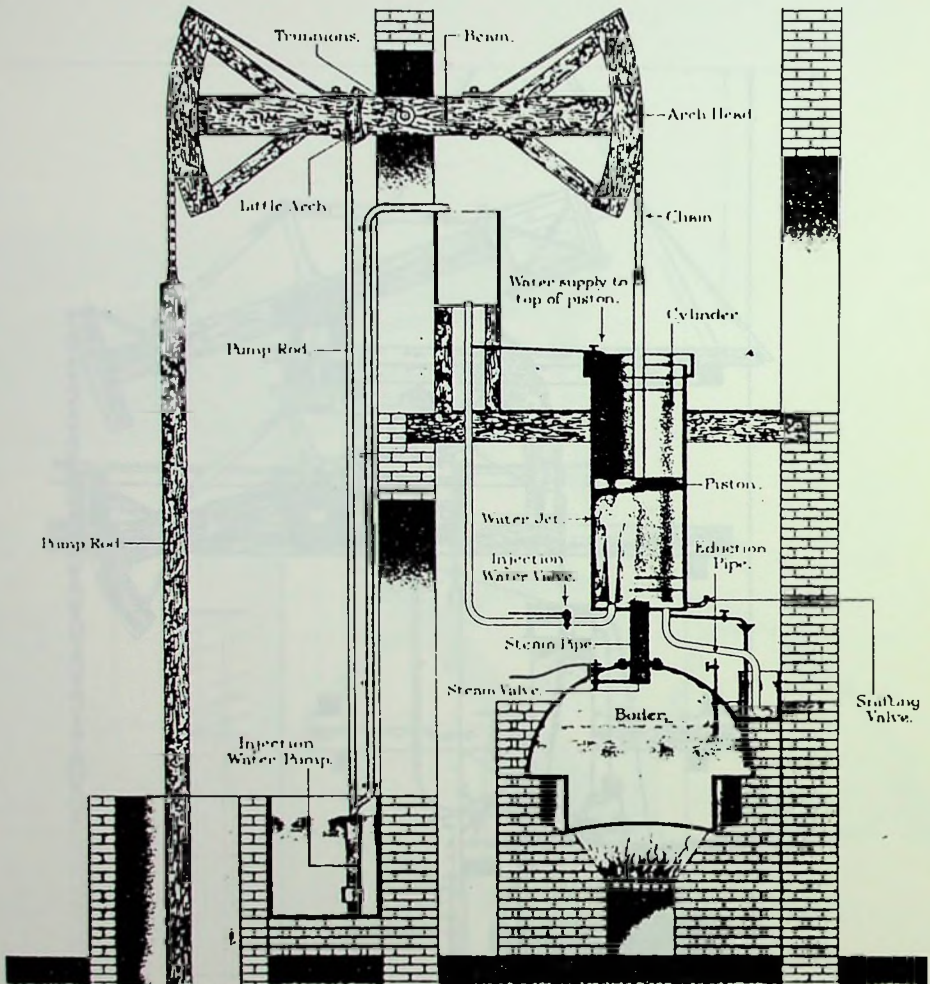
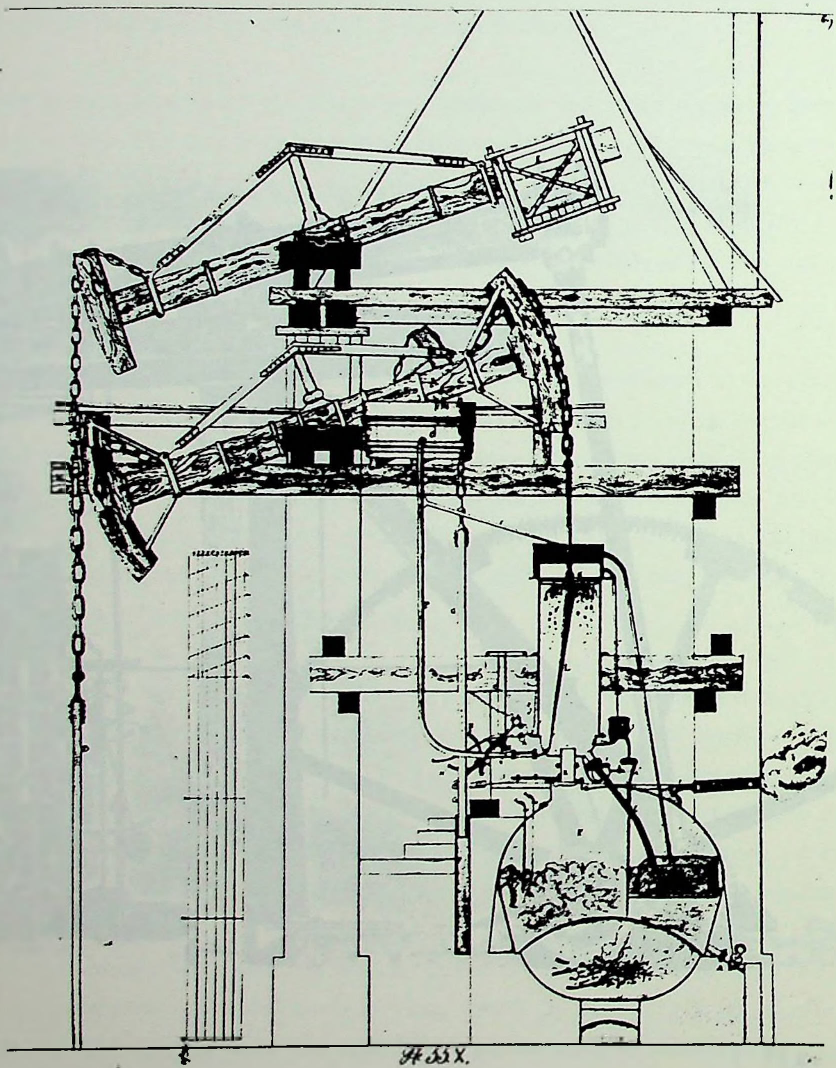


Trunnions.
Beam.
Arch Head
Little Arch
Chain
Water supply to top of piston.
Cylinder
Pump Rod
Piston.
Water Jet
Pump Rod
Eduction Pipe.
Injection Water Valve.
Steam Pipe
Steam Valve.
Boiler
Snifting Valve.
Injection Water Pump.

(Fig. 7.)



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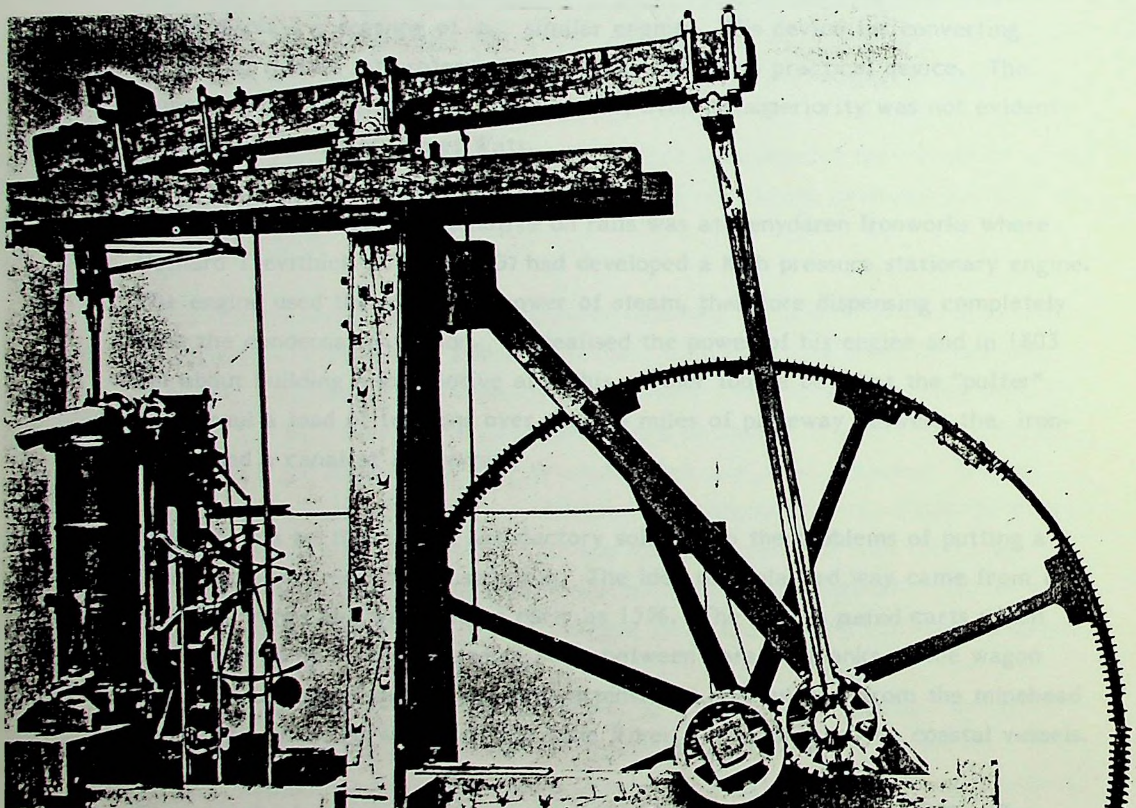


(Fig. 9.)

THE FIRST ENGINES IN MOTION.

The first steam locomotive to be built was in Paris in 1770, which was a generation ahead of the successful English locomotive, but had apparently no effect on the later investigation. Nicolas Cugnot (1725 - 1804) demonstrated in front of army generals a three wheeled self propelled steam wagon, which may have been intended to carry or drag artillary pieces behind it (Fig.10.). A copper boiler which held perhaps 400 gallons of water, supplied steam to two high pressure steam cylinders, which were mounted vertically above the single front driving wheel by means of a ratchet device.

The pistons alternated the downward movement therefore supplying impetus to the wheel. The influence is said to be from a German refrence book of 1724 which displays a drawing of a similar engine . His device for converting reciprocal motion into rotary motion is the first such practical device. The Cugnot device is remarkable for the time, even its superiority was not evident to the acute mind of James Watt.

The birth of the steam locomotive on rails was at Penydaren Ironworks where Richard Trevithick (1771 - 1833) had developed a high pressure stationary engine. The engine used the expansive power of steam, therefore dispensing completely with the condensation action. He realised the power of his engine and in 1803 set about building a locomotive after his partner took a bet that the "puffer" could haul a load of ten tons over the ten miles of plateway between the iron-works and a canal at Abereynon.

Nevertheless by this time a satisfactory solution to the problems of putting a locomative on tracks had just begun. The idea of a planked way came from the needs of mines and was used as early as 1556. The miners pushed carts which were steered by a stud extending down between paralled planks of the wagon way. In Newcastel these were used extensively, to haul coal from the minehead to the straithes and wharfs of the Tyne River, for loading on the coastal vessels.

Flanged wheels were used on wagons pulled by horses as early as 1734. The rails were improved from time to time, firstly by fastening a series of cast iron plates, each several feet long and 3 to 4 inches wide to wooden stringers of the railway. Later cast iron plates bars provided standing flanges at either side of the iron tracks, thus eliminating the need for flanged wheels.

The plateway used for Trevithick's wager comprised of cast iron angle plates which standing flanges supported on stone blocks. The locomotive was designed on similar lines to the pumping engines, with one cylinder, crank and connecting rod, to produce rotary motion. He used a larger flywheel to make the motion continuous and avoid stalling on the dead centres. (Fig 11) The clyinder was 8½ inches diameter with a long stroke extending into the boiler barrels. The trials was successfully completed in just over four hours.

In 1805 Trevithick demonstrated his "Catch me who can" on a circulartrack to a paying audience near the site of the present Euston station. Hoever there were difficulties, and a continuous breaking of the rails which ended the show. Many observers of his engine, noted slipping between the wheels and the track, which was to have further repercussions.

An enginewright named Blenkinsop made an attempt to co-ordinate the design of the track and locomotive. Blenkinsop thought that the only way to haul a heavy load up a slope, was by using a geared driving wheel on a fixed rack on the track. He also dispensed with the large flywheel by having two cylinders driving alternatively on the same axle, which carried the toothed driving wheel.

William Brunton proposed and patented in 1813 a locomotive that would be moved by mechanical feet mounted on jointed walking rods which extended like legs from the engine.

These designs arose out of difficulties of obtaining sufficient friction between the driving wheels and the rails. That much of these, difficulties existed only in to the minds of builders made it no less real. Trevithick had tested this problem in 1801, when he and friends dragged on spokes of a carriage rotating the wheels, and determining that it would climb any slope. However despite later tests a general doctrine was diffused that locomotives could only be used when the track was dead level. This was not in accordance with the facts though believed and was also imported into America. In England on grades of even one in one hundred cars were dragged up by ropes using stationary engines.

It was not until 1836 when William Norris of Philadelphia challenged the doctrine and dramatically, that its hold upon the engineering mind was shaken. He drove a locomotive and loaded passenger car up a slope of seven in one hundred.

The much celebrated "Puffing Billy" by William Hedley and Christopher Blackett continued the developement of locomotives. It transmitted power by two cylinders to both axles by a series of gears beneath the massive frame. (Fig 12). The use of thooted gears to transmit power would seem to have eminated from clock and instrument makers, who were already proficent with power transmission. Hedley encased the vertical cylinders in the boiler to keep them hot and directed the exhaust into the chimney to increase the blast in the firebox.

George Stephenson (1781-1848) the man who was to epitomise and consolidate the whole development, built his first locomotive at Killingworth Colliery in 1814. "The Blutcher" as he called it was much similar to Hedley's Puffing Billy". With his second engine (Fig 13) he powered the pour wheels by the cylinders, their disposition being maintained by an endless chain over a thoothed gear on the axles.

In 1820 the manufacture of rails took a major step forward. John Birkinshaw produced wrought iron rails lay the rolling process. Stephenson had previously introduced a half lap joint between adjacent rails thus reducing the wear on locomotives, that butt joints had caused. The rolling process produced malleable iron rails of 18 to 20 feet long.

Even by 1828 Stephenson was concerned about the appearance of his locomotives and spoke about "endeavouring to the size and ugyliness of our travelling vehices" This seems to have been in response to Timothy Hackworths "Royal George" which was considered an advance visually on his earlier designs. Stephenson responded with his "Lancashire witch" by placing the cylinders in an inclined position at the rear end. (Fig 14) He also incorporated two fireboxes and converging flves, this was the very beginning of the multi-tubular boiler.

Railways had now been in operation in various forms. The stocton and Darlington line which had been operated by horse drawn coaches was the first carrier to employ locomotive power in 1825. This was mainly due to Stephensons foresight in building the line to suit locomotives.

Many railway companies were chartered quickly after the conversion of the Darlington line including the Liverpool and Manchester Railway. The L. and M.R. was constructed under the guidance of Stephenson, who insisted on a direct route, and overcame many geographical dufficulties in achieving this. When it was completed the decision to use locomotives was not unanimous but Stephensons achievement on the line construction won the day. Stationary engines were to be used for haulage on the sloped sections.

To decide which locomotives to use, the directors set a competition with a prize of £500 for the locomotive with best fulfilled certain strict running conditions.

Before this however , certain very important improvements were being made in boiler design. Mare Sequin, who had experimented with steam on the St. Etienne line was making a multi-tubular boiler, which gave much better steam generation. The tubes ran from the firebox to the exhaust, providing a much larger heating surfact. He induced a draught by rotary fans which was a weak point of his design.

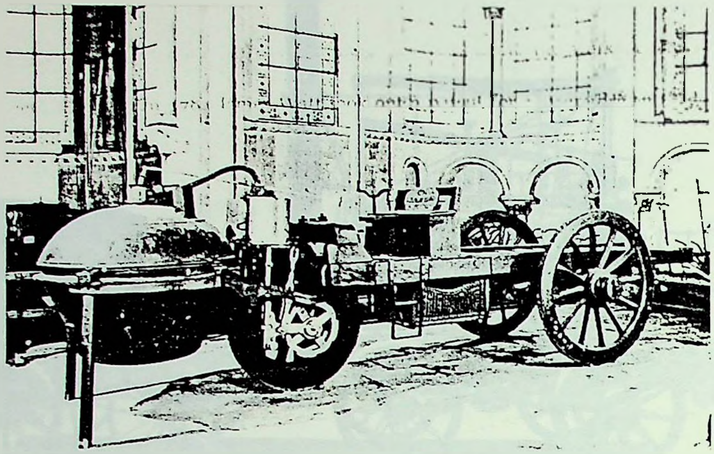
Stephensons entry for the competition the aptly named "Rocket" (Fig 15). used twenty five small tubes which carried the gases of combustion, from the single fire to the flue. He also used the inclined cylinders of the "Lancashire Witch" but dispensed with coupling of the wheels, and drove the rear wheels only. This was in an attempt to attain a higher speek. The remaining feature of "the Rocket" was the blast pipe. A narrowing cone leading to a small orofice through which the exhause steam was passed, "impared great speed" to the exhaust, which acted as a draught to the fire. Stephens introduced what most have seemed radical at the time, a bright colour scheme for his engine. It was a bright yellow with black picked out points and a white chimney.

The other engines challenging for the prize were that of Timothy Hackworth called the "Sanspareil" and Erricsson and Braithwaite"s Novelty of mess". The Sanspareil represented only what had already been achieved in engine design at the time, coupled wheels, vertical cylinders and a return flue builer(Fig 24)

"The Novelty" who's appearance displayed similarities to that of Cugnot, was a very light engine which had an injenious but totally impractical boiler. (Fig 16) The boiler was fired from the top and draught induced by a bellows, with the fuel and water being carried on the main frames. The engine was characteristic of what was to pioneer American locomotives of that time.

All was set for what was known as the Rainhill Trials on the Liverpool and Manchester Railway in 1829. The engines performed admirably but an overwhelming success was attained by "the Rocket". It travelled at 24 miles per hour with a carriage and passengers, while pulling three times its weight it attained 12½ miles per hour. The Rocket had no hitch compared to its rivals. The "Sanspareil" prooved to be its closest competitor but lacked the speed when unladen. The swedish John Erricssons "Novelty" prooved to be the fastest, having attained 32 miles per hour, but it was dogged by breakdowns of its complex boiler, which proved inaccessable to reach. Considering Erricssons success and fame years later in America it is felt that he was unfortunate in the trials.

Locomotives of the Rocket type became the first passenger engines on the L. and M.R. The opening in 1830 however was scarcely auspicious. Firstly it was unveiled by the Duke of Wellington who was most unpopular. The weather was vile and the right Hon. William Huskisson was run down and killed by the "Rocket". With all cermony abandoned there was the first whiff of a new crime. However the gloom did not prevent the railway from being a success, and the liverpool and Manchester Railway began what was the most momentus developement in the entire history of steam locomotion.



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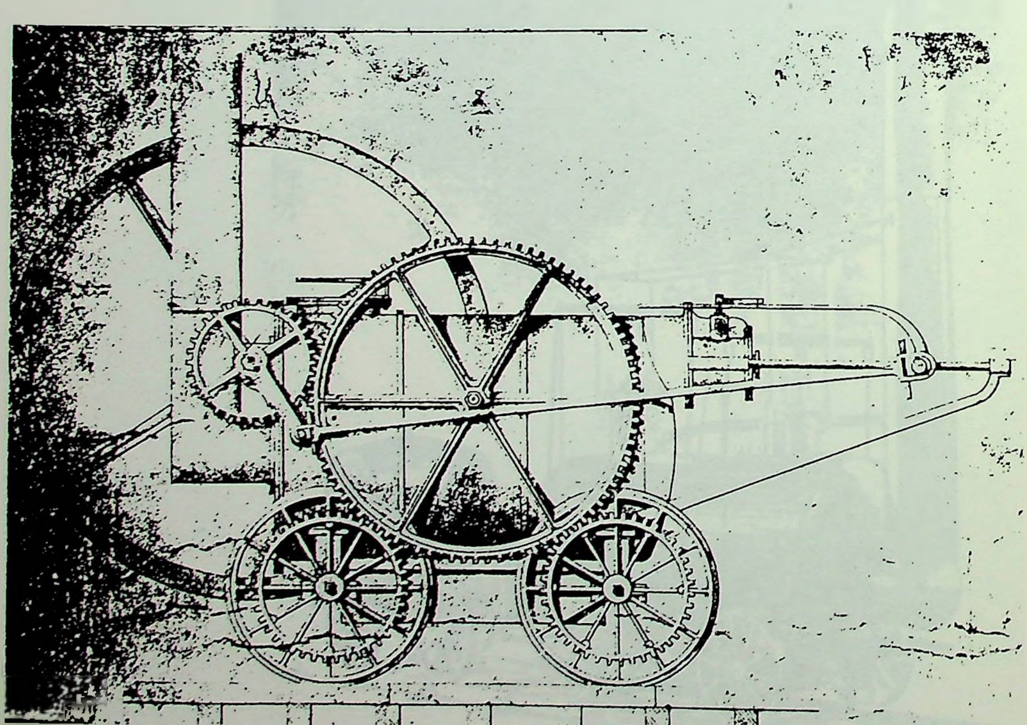

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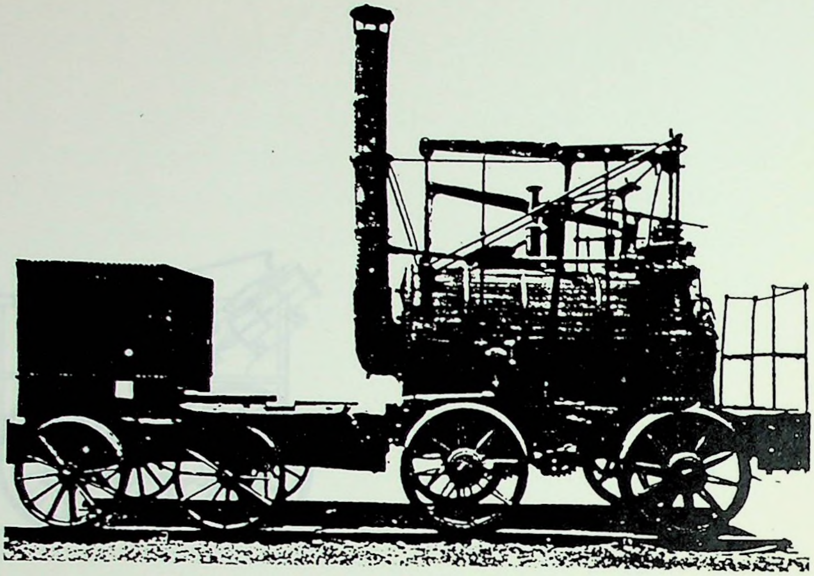

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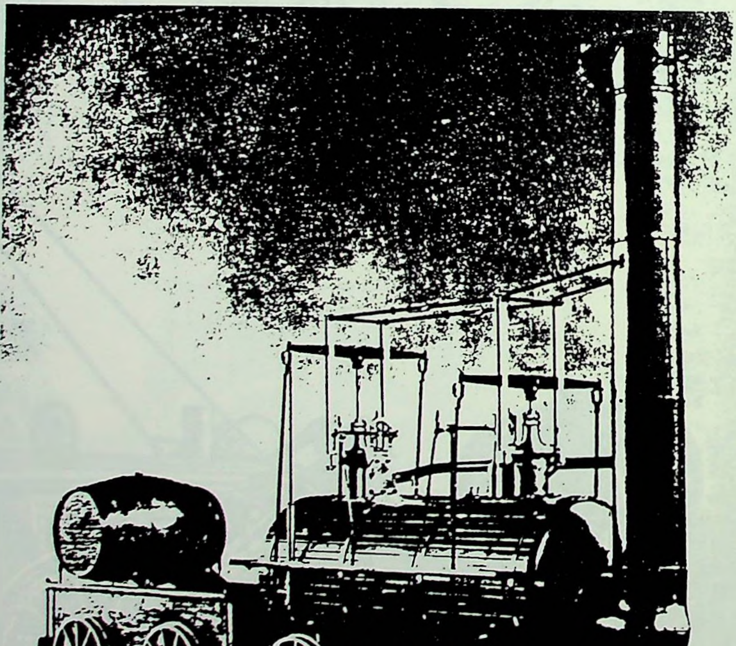

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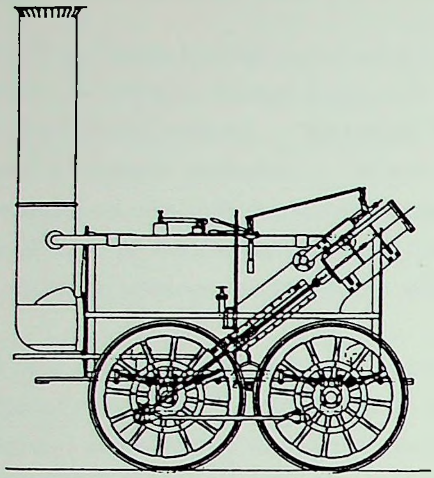

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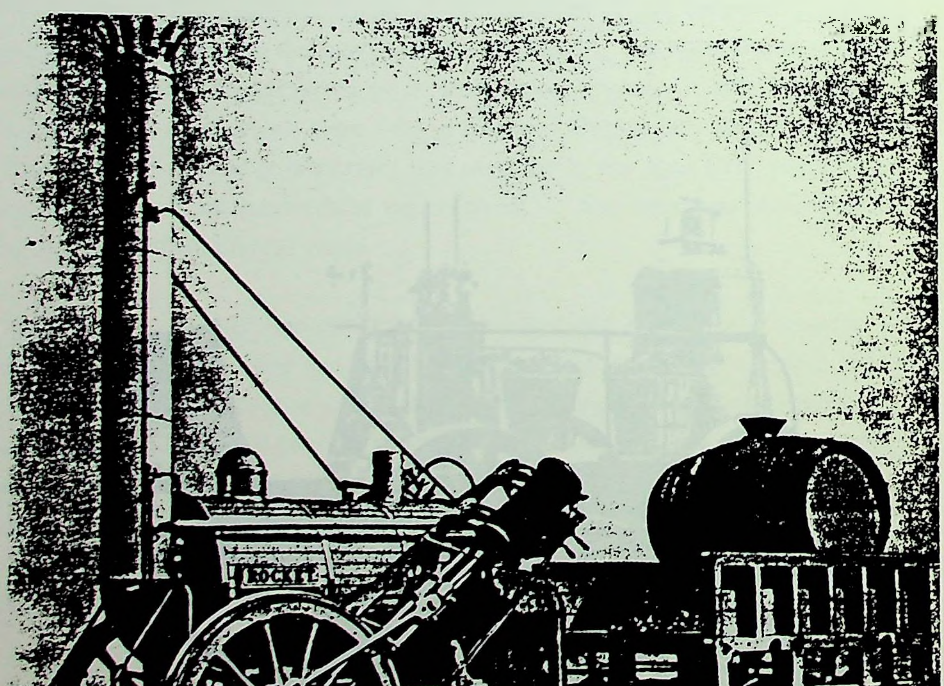

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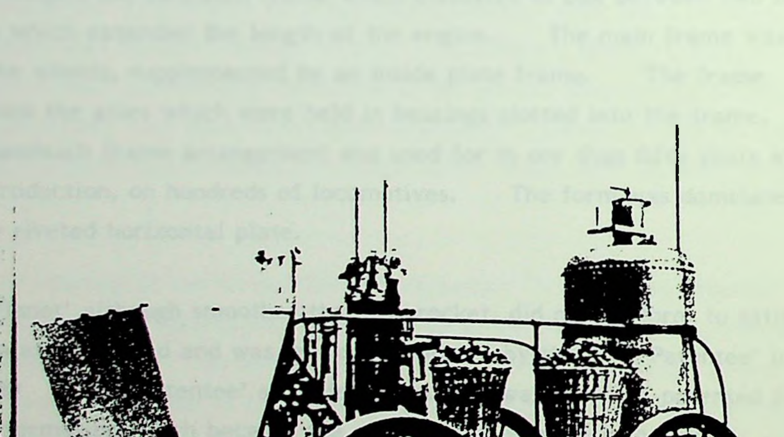


(Fig. 16.)

The Development of the Locomotive Form as a True Machine Product.

After the overwhelming acceptance by companies and public alike of the steam locomotive, George Stephenson set out to improve the performance of his "Rocket" engine. He rebuilt it with a more dignified chimney upon a separate smokebox. In place of the original tender and barrel he designed one with the water container enclosing a coal bunker. The final form of the engine had the cylinders lowered to a near horizontal position to improve the steadiness while running at high speed.

In 1830 after building only a few improved "Rocket types he introduced the 'Planet' type (Fig. 17) which was an entirely different concept of engine layout, and virtually turned the machine back to front. He placed the cylinders incide the frame and at the front beneath the smokebox. This must have appeared contradictory initially, as the pistons would be pushing in the opposite direction to the engine motion.

He developed the sandwich frame which consisted of oak between two iron plates which extended the length of the engine. The main frame was outside the wheels, supplemented by an inside plate frame. The frame accepted the axles which were held in bearings slotted into the frame. This sandwich frame arrangement was used for m ore than fifty years after its introduction, on hundreds of locomotives. The form was dominated by the riveted horizontal plate.

The 'Planet' although smoother than the rocket, did not perform to satisfaction at full speed and was quickly replaced by the 'The Patentee' in 1834. (Fig. 18) The 'Patentee' so called because it was the first patented 2-2-2 wheel formation which became the precursor of express locomotives. It was basically a 'Planet' with an extra pair of trailing wheels, supporting an enlarged firebox. The extra wheels provided a great improvement in the riding qualities, and before the end of the decade were running safely at sixty miles per hour.

Aestetically the 'Patentee' was a remarkable advance upon the 'Rocket' in a short space of five years, and displayed in embryonic form the hallmarks of Victorian steam locomotive design. The engine and tender seemed to belong, and were only spoilt by the clumsy chimney which gave a heavy appearance to the front.

The first attempts to consider the driver are seen here, albeit by only side, rails and a foot plate. Thousands of 'Patentee' were ultimately built and this type were the first locomotives to be used on railways in Belguim, Holland, Italy, Germany and Russia.

The other classic type of locomotive was designed by Edward Bury with the assistance of William Norris of Philadelphia. It was constructed on a bar f rame with inside cylinders and a 'haystack' firebox, which was a distinctive feature of his designs (Fig 19) It was introduced into America where it was much modified, elaborated, and enormously enlarged and remained the orthodox steam railway engine for well over a century. Bury who pursued a long course continued to introduce small bar framed designs until 1846 even though they were outclassed by then.

By the mid 1830's attention began to shift away from the industrial North of England where railways were flourishing, to the west, where I.W. Brunel's Great Western Railway was to construct seven foot broad gauge lines. Until then a gauge of four ft. eight and a half inches had been settled upon as suitable for railways by G. Stephenson, although their were isolated examples that did not conform to this. Although a seven ft. gauge seemed eccentric, had it overcame the battle of the gauges that was to follow, railway history may have taken quite a different course. The loading of trains has been restricted by the guage of the track right up until the present day.

For the opening of the Great Western Railway in 1838, Brunel ordered twenty locomotives from various manufacturers of which only two by G. Stephenson proved successful. Brunel not only specified that they should be big and fast but as "handsome as could be made". When he received the 'North Star' and 'Morning Star' he was overwhelmed by their appearance and wrote that they would have been a beautiful ornament in the most elegant drawing room. The 'North Star' was quite similar to the 'Patentee' except for a noticeable attempt to improve the overall effect of the dome, safety valve, and chimney. These were to become areas for a concerted effort, and greater attention to detail in creating an identity for their company. (fig 20)

In general certain trends had evolved since the rainhill trials. Boilers generally had an outer lagging of tenoned and grooved timber (usually mahogany) which ran in strips length ways along the boiler. They were usually finished by staining and varnishing. Bands of polished brass or painted metal were bound around the wooden strips. The exterior of the firebox had been left bare initially with rivet heads showing, but it soon became practice to lag these with wood. The wooden lagging was not essentially for estetic purposes as it reduced the heat losses through the boiler and firebox surfaces.

The firebox had taken three distinctive shapes by 1840. The most extensively used was that originated by G. Stephenson, which was slightly raised with the same front outline as the boiler. The distinctive 'haystack' shape of e. Bury which was initially made of cast iron and later copper. The 'Gothic' shape was portrayed in the engines of D. Gooch which had large capacity boilers (Fig 21). The 'Gothic' title was given b ecause it had a somewhat pointed pyramidal shape to the top of the casing.

Chimney design had changed since the 'Rockets' "white pipe with a crown top" and now was an iron casing built up in two or three sections wich curved out to join the smokebox. Boiler mountings were beginning to display a certain elegance of their own with polished brass or copper finish.

No protection was given to the drivers apart from handrails however they must have welcomed the high 'haystack' of 'Gothic'fireboxes for the added shelter they provided.

Thomas Russell Crampton (1816-1888) was an Englishman more honoured in France and Germany. In France the phrase "prendre le Crampton" was a colloquialism for going by train. His engines were conceived on the lines of a stern-wheel steamer to lower the centre of gravity. By putting the single large driving wheels right behind the firebox he could use smaller diameter wheels below the boiler (Fig. 22). He used outside cyclinders with large eccentric rods controlling the valve gear.

The overall appearance was quite different than what had been previously exhibited and it was not accepted. This was partically because it appeared foreign and unconventional to the English eye. Adherence to convention was an important asset in achieving success with locomotive design as it was in many other areas of creativity .

The drivers were positioned between the two distinctive splashers and protected somewhat by a front deflector with portholes. A practical aspect of the design was the accessibility of working parts, under the high running rail. The first Crampton locomotives were built by Tulk and Ley during the period 1846-47.

George Stephenson was engaged at this time in trying to develop a long boiler design, with a low centre of gravity. This was to increase boiler efficiency and therefore output. However he was restricted by the length of turnables in use in stations and tried to overcome this by compacting the wheels together. He tried this by placing the wheels between the smokebox and firebox with a considerable overhang each end. The whole purpose was defeated when they proved unsteady at a high speed, so they were only used for freight dtuies.

While Stephenson and Crampton were engaged in experimental work other locomotive builders were engaged in progressing improved variations of the 'Patentee'. Notable among these were Sharp, Roberts, and Company who built the 'Jenny hind' designed by David Joy for E.B. Wilson (Fig. 23). This has traditionally been considered to be the finest example of design of the period in aestetic terms. Another variation of this design by the same company was the first used on the Kingstown to Dublin line in 1842. The chimney is of much better proportion, while their is greater attention to detail on the 'Jenny hind'. The use of classic columns for the fluted dome and safety valve does not increase its visual appeal. The dome is very similar to that used by Timothy Hackworth on 'Middlesboro' No. 9 for the Southern and District Railways ten years earlier (Fig. 24)

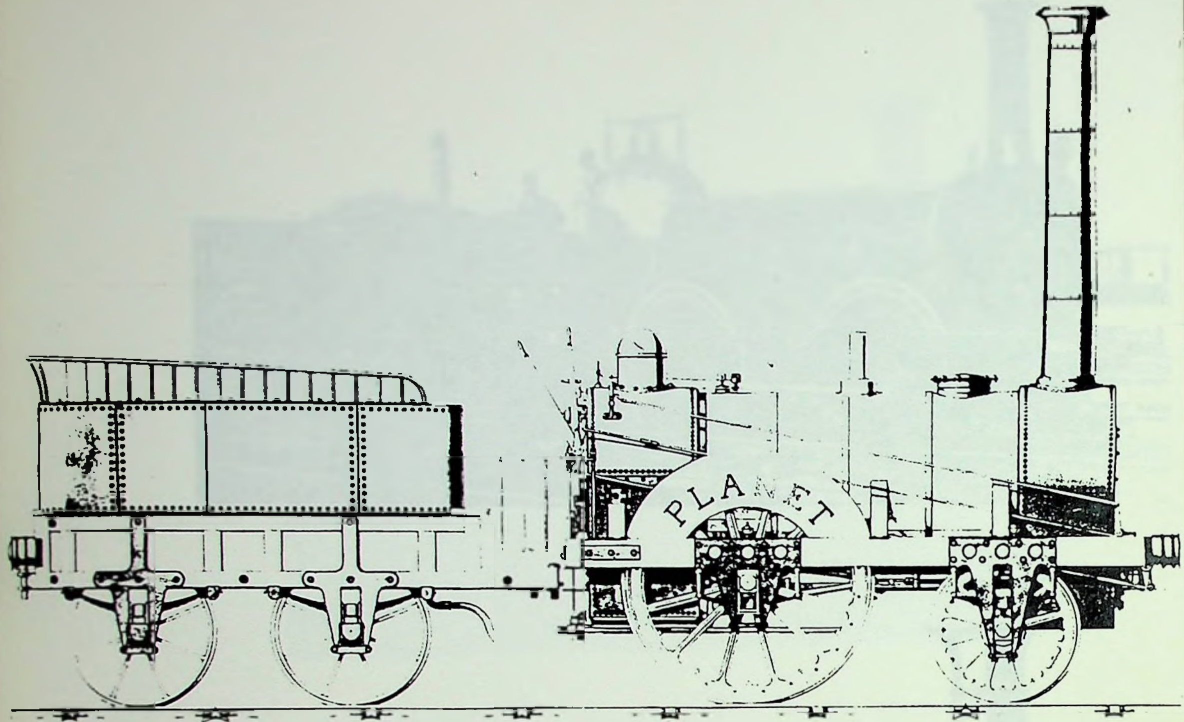
The feature of the slotted wheel splasher used by Crampton is also evident on the 'Jenny hind'. The use of side sheets enclosing the handrails is first seen here, and used the now familiar quarter circle cutouts on the coloured highlights.

The finest example of the use of a coherent form combining all three, projections from the top of the locomotive, is seen on the 'Plews' of the Newcastle and Bewick Railway by R. and W. Hawthorn. (Fig. 25). This was a flared sheet with clean curved lines which were well combined for safety valve, dome, and chimney. The direct influence of these features is difficult to access, but it does seen to have been influenced by decorative metal work pieces for household use.

One other notewordy locomotive of the period was the 'Crew type' by Alexandre Allan (Fig. 26). The persistent breaking of the crank axles on the lines near the Crew junction induced Allan to design an engine with the cylinders to the outside as had been done previously. The engines were distinguished by having the cylinders linked to the large double frame, by a flowing curve extending from the smokebox. The cylinders were slightly inclined, with the side rods located between the frames in a cut-out, which permitted access to the cross head, slidebars and piston assembly.

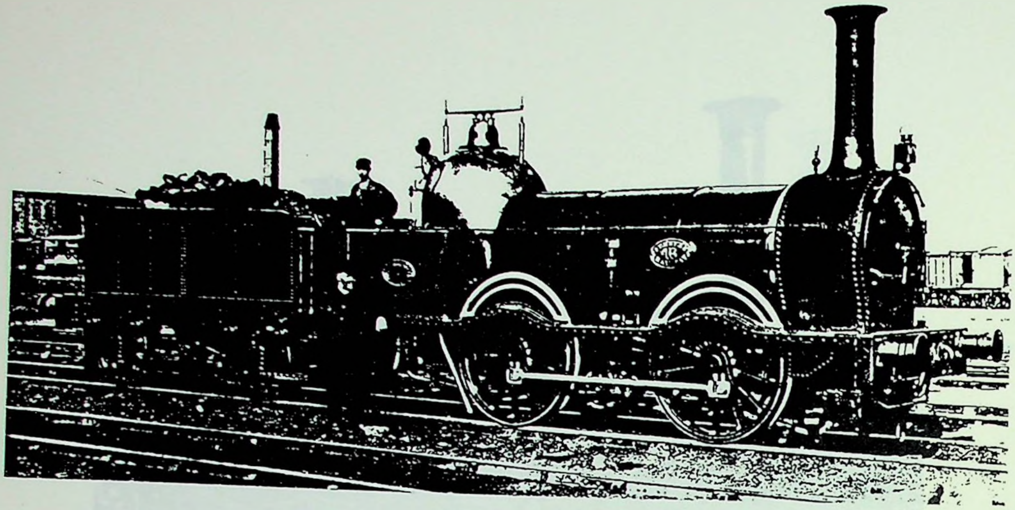
The 'Crew type' locomotives were built in France as early as 1844 by William Buddincom under licence, and were widely known as 'Le Buddicom'. The'Crew type' were also characterised b y their neat boiler mountings with Salver valves which were in keeping with the overall visual simplicity.

The bringing together of the engineering design and aestetic appeal had now become an important aspect of the success or failure of a locomotive. The crudity of manufacture no longer made itself apparent in the finished product and the outward aspects were one of great attention to detail. This is the most obvious aspect of the design during the period 1830-1851, namely that it was almost alone the example of true machine product design. This seems to have developed naturally through the constant search for improvement and refinement, and assumed shape through this process.



(Fig. 17.)

(Fig. 18.)



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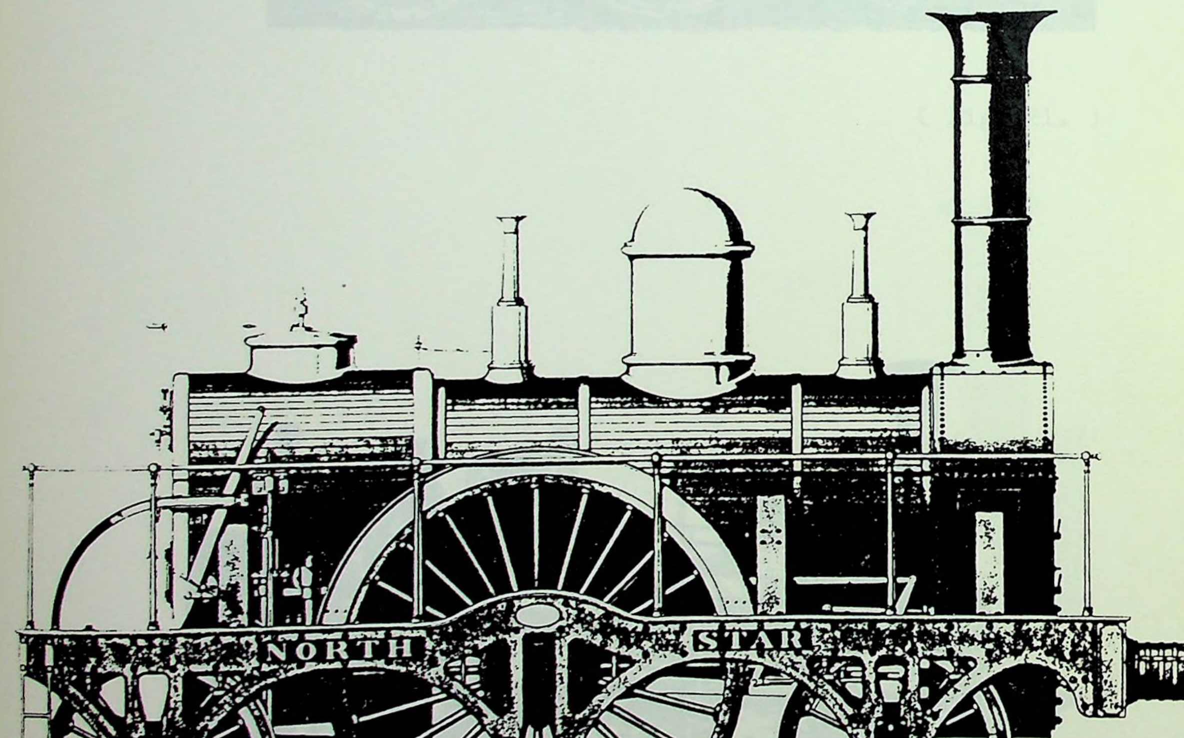

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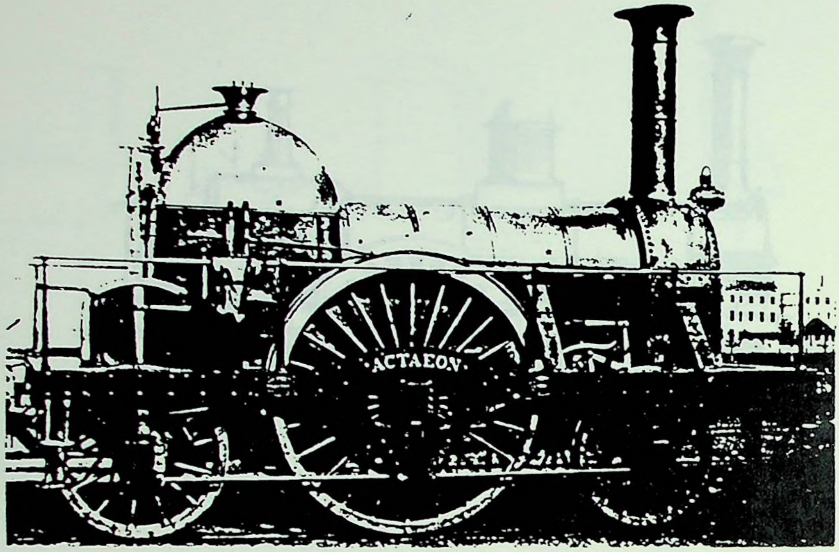

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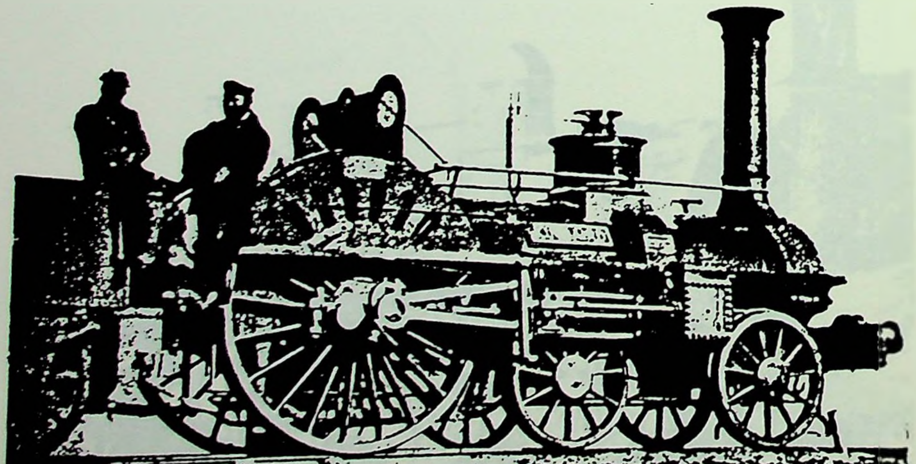

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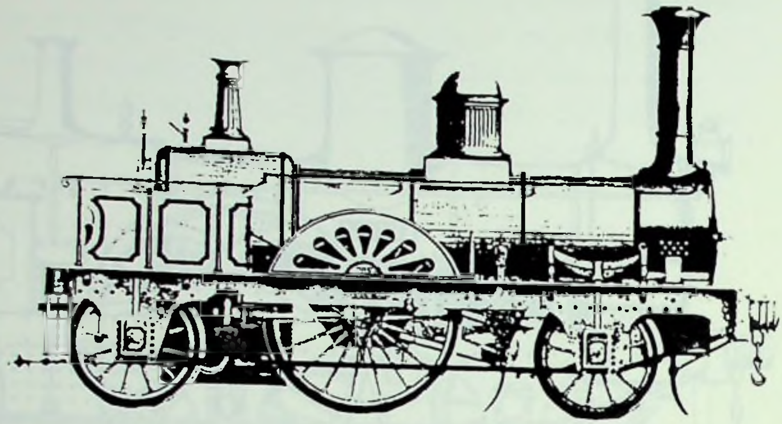

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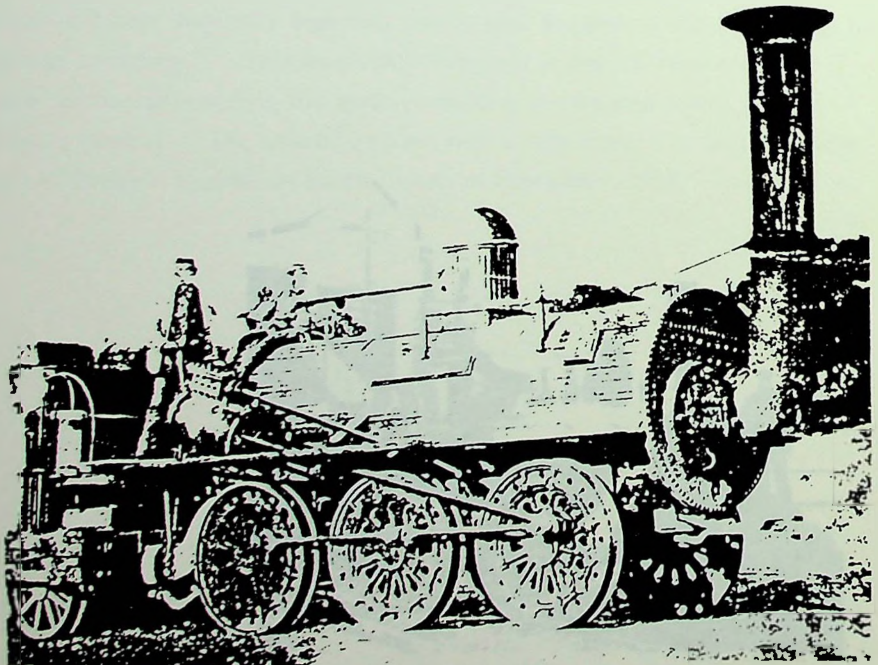

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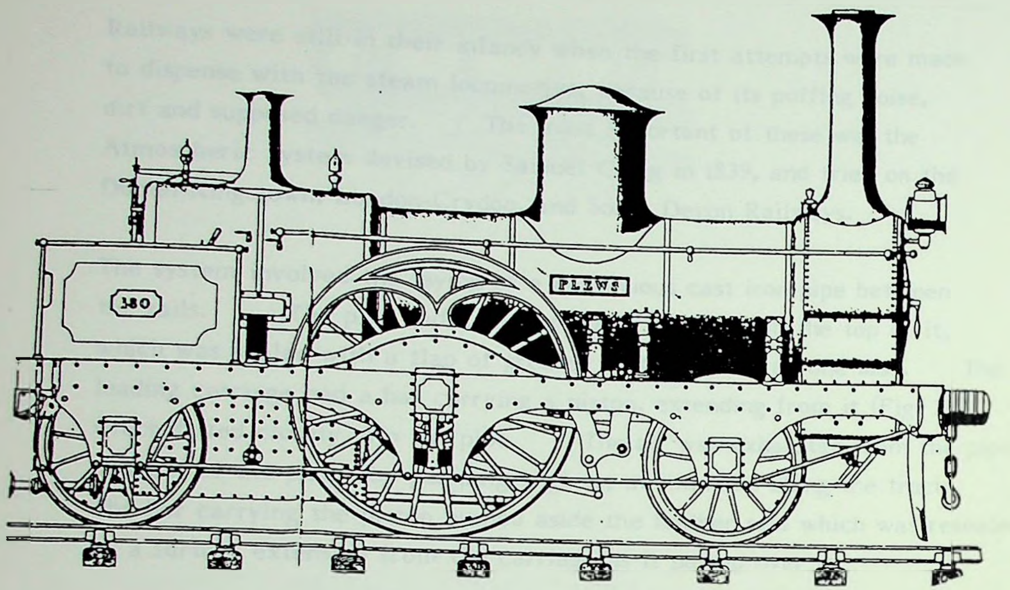

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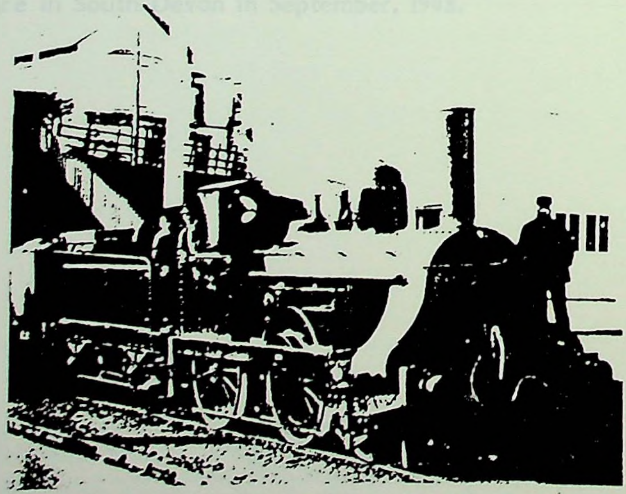


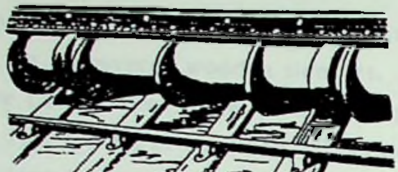
(Fig. 26.)

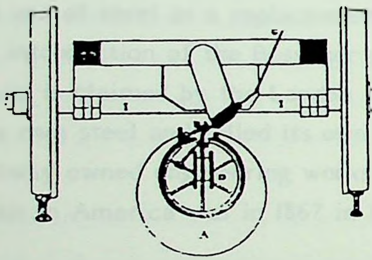
The Atmospheric Traction System.

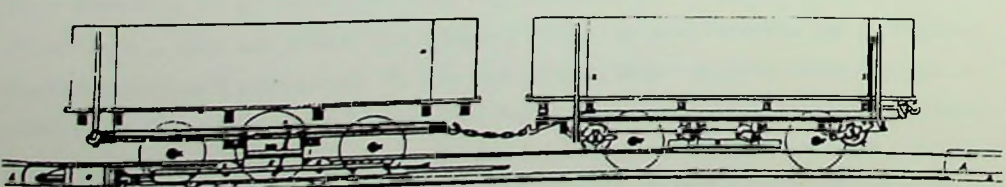
Railways were still in their infancy when the first attempts were made to dispense with the steam locomotive, because of its puffing noise, dirt and supposed danger. The most important of these was the Atmospheric System devised by Samuel Clegg in 1839, and tried on the Dublin-Kingstown, London-Crydon, and South Devon Railways.

The system involved the laying of a continuous cast iron pipe between the rails. The pipe had a slot of about 2½ inches in the top of it, which was sealed with a flap of greased leather, fixed on one side. The leading carriage had a bar carrying a piston, extending from it (Fig. 27) which fitted closely into the pipe. The air was exhausted from the pipe in front of the piston by pumping engines, at intervals along the track. The bar carrying the piston pushed aside the leather seal which was resealed by a further extension from the carriage as it passed over it.

Sanguine people expected the rapid obsolecence of locomotive traction at the time, however junctions raised very serious problems, which resulted in the building of the first flyover in the world in South London. The wear and tear was very high and finally rats knawed at the leather for its grease covering. This eventually resulted in loss of vacuum in the pipe section preceeding the piston resulting in stranded trains with no motive power. The overall system was a very expensive failure ending in I.V. Brunels closure in South Devon in September, 1948.







(Fig. 27.)

The Railway Track.

By 1845 railways in many countries were laid with iron rails keyed into a common chair on transverse wooden sleepers. A heavy or rough riding locomotive could cause the ends to be displaced and lift up. Some lines used flat footed or inverted 'U' section rails on longitudinal baulks, kept in place by cross ties. This type called the strap rail was used in America and showed a disasterous tendancy to curl up and pierce the floors of passenger cars.

'Fish-joints' formed of narrow plates on each side of, and bolted through, the webb of each pair of rails, were patented by Bridges Adams in 1847. Peter Bruff obtained the patent for Eastern Counties Railways and they became generally used from 1859's onward. it was a much simpler arrangement which made the track much safer.

The successful use of steel as a replacement for iron in rails was possible only after the introduction of the Bessimer process in 1856. The first use of steel rails is claimed by the London and North Western Railway which made its own steel and rolled its own rails at Crewe where it had the largest railway owned engineering works in the world. The first use of steel for rails in America was in 1867 in Pennsylvania.

Rails gradually increased in cross-section which was proportional to the increase in weight and speed of trains. By the year 1900 flat bottom rails in America had reached 100 lb. per yard while in England with much lighter rolling stock, bulk head rail at 90 lb. per yard was massive by contemporary standards. It was the development of rails which enabled the main line railways to become a commerical success.

BRAKING SYSTEMS.

The use of breaks was not considered a necessity on early locomotives. With the development of more powerful engines and a railway system, it had become necessary to provide means of control. Engineers had not seem fit that control should be enforced on their engines . The omission of safety values on early locomotives is an example of this . They were also reluctant to put any form of brake on a locomotive and argued that any form of brake shoe running on a wheel would be "injurious" to the machinery . This seemed to stem from the number of broken axles on engines.

In consequence the early form of brake consisted of wooden blocks on the tender wheels . They were supported on an iron framework linking all blocks connected to a handle or wheel . (Fig 28) The fireman applied the brakes on the tender. Brakes on the train were also present in the form of break vans at the front and rear . These were applied by hand by a guard who received whistle code signals, from the driver when he wanted to stop. This situated persisted on some trains until the 1870's, when blocks were installed on locomotives (Fig 29) The time delay and lack of coordination in application made the system completely inadequate. Combined with the signalling system it seems nowadays like an extraordinary haphazard and dangerous situation.

The continuous Automatic air brake wsa developed and patented in 1873 by George Westinghouse (Fig 30). The brake acted on all vehicles of a train should the train break in two. It operated by means of compressed air reservoirs in each vehicle, connected by a continuous pipe. The pipe pressure controlled the brake pistons during application. If a train broke in two the pipe pressure would be reduced to zero as the pipe coupling disconnected. This allowed the air from the reservoirs into the brake pistons by means of a triple value, and activated the brakes on both sections of the train. The tiple value was an essential part of the system.

In the Newark Brake trials of 1875 the system stopped a train weighing 203.3 tons travelling at 52 miles per hour in a distance of 913 feet and in a time of 19 seconds . The air brake was adopted in Europe and America but in England various types still prevailed. It was not until a major disaster near Armagh in 1889 when 78 people were killed, that leglislation was rushed through Parliment, which made automatic continuous power brakes on all English railways compulsory. The brakes not only facilitated the rapid stopping in emergency but made possible great improvements in the timing of express trains.

By 1880 the vacuum brake system was also in use. Its advantages were in its control of braking in non-emergency situations. The brake had a time lag between the front and back of the train when it broke in two,which was overcome in 1910 with the inclusion of a Direct Admission value in the system. This allowed air from the atmosphere into the brake cylinders, which were in vacuum when the train pipe disconnected.

The brakes could be partially applied and released without having to release completely as in the Westinghouse system. Its disadvantage is the time taken to release the brakes after they have been fully applied. This may be three minutes for a long train.

The westinghouse system is retained in part in present day electro-pneumatic braking.

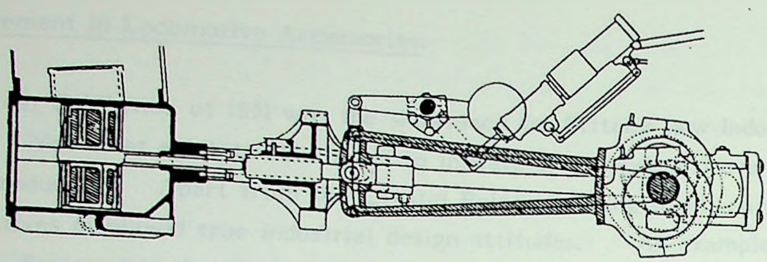
Valve Gear.

Valve-gears for admitting and using the steam expansively had been developed in the 1840's, notable types being those of Daniel Gooch, Alexandre Allan and Stephenson Howe gear. In all these the valve motion was controlled by eccentrics and a sliding reverse link (Fig. 31). Earlier valve gears had been used soely for the admission and exhaust of steam to and from the cylinders. There was no means of varying the cut off through a reverse link. Very early gears were usually indirect, the eccentric rods engaging by means of hooks with rockers, which conveyed their motion to the valve rods. (Fig. 32).

The latter part of the nineteenth century saw experiment and innovation in the design of valves and valve gears. Although slide valves remained in use, attempts to produce piston valves were being made but these were premature. Various radial valve gears were designed, one of the most successful being by Egide Walschaerts in Belgium (Fig. 33). This was adopted in various foreign countries but it took many years before British Railways took it up, except those built for export. It did, however, become the standard gear on British locomotives in the twentieth century.

Walschaert's gear differed considerably from established link motions and this was enough to make Victorian locomotive engineers cautious of it. The eccentric motion is derived from a single return crank outside the driving-wheel crank.

Anther type of valve gear was that of David Joy (Fig. 34) which was used in the late nineteenth century, especially by British Rail. Its weak point which became uncomfortably apparent when it was applied to larger, locomotives, was that its arrangement involved a piercing of the connecting rod. This resulted in some bad break downs through the fracture of the rod while running.



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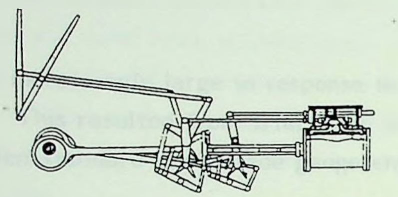

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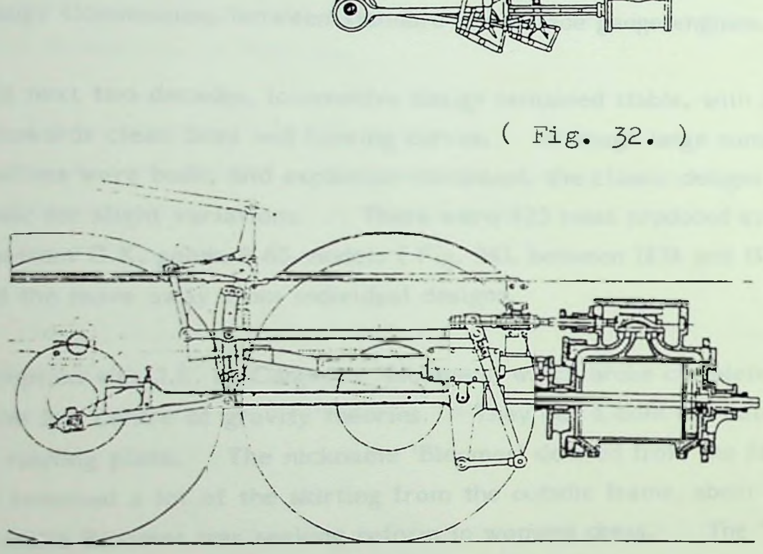

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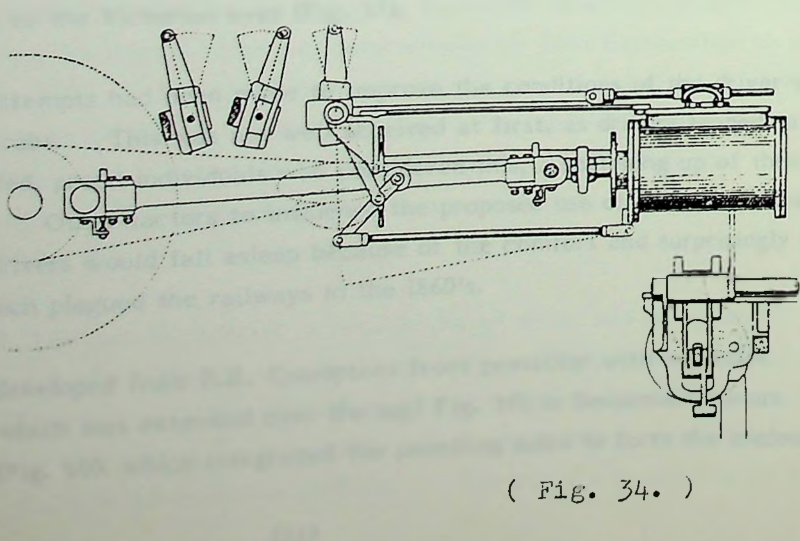


(Fig. 34.)

Improvement in Locomotive Accessories.

The Great Exhibition of 1851 was the showplace for Britains new Industrial skills. Yet most exhibits attempted to imitate craft work and over decorate their produce. Apart from the Crystal Palace building itself, only the locomotives displayed true industrial design attitudes. An example of the engines displayed is the 'Lord of the Isles' by Daniel Gooch (Fig. 35). This was the basic type which remained in service on the broad gauge line until it closed in 1892.

Locomotives had now become increasingly large in response to the superiority of the broad gauge engines. This resulted from trials held in 1846 by the Gauge Commission, between standard and broade gauge engines.

For the next two decades, locomotive design remained stable, with a general trend towards clean lines and flowing curves. Although large numbers of locomotives were built, and expansion continued, the classic designs formed the basic for slight variations. There were 923 mass produced standard Ramsbottom C.X. goods 0-60 models (Fig. 36). between 1858 and 1872 which showed the move away from individual designs.

An exception was J.E. McConnell's 'Bloomers' which broke completely away from the low centre of gravity theories. They had a bold tall outline and a high running plate. The nickname 'Bloomer' derived from the fact that he had removed a lot of the skirting from the outsdie frame, about the time Mrs. Amelia Bloomer was seeking reform in womens dress. The 'Bloomers' locomotive eventually came in three sizes which proved versatile. They were coloured a brilliant vermillion red which must have posted a brave spectacle to the Victorian eyes (Fig. 37).

Several attempts had been made to improve the conditions of the driver with enclosed cabs. This was not well received at first, as drivers tended to be strongwilled, proud individuals who considered this, a softening up of their position. Other factors to influence the proposed use of cabs were; that perhaps drivers would fall asleep because of the comfort and surprisingly vandalism, which plagued the railways in the 1860's.

The cab developed from E.R. Cramptons front protector with portholes (Fig. 38) which was extended over the top(Fig. 39) to Benjamin Connors example (Fig. 40). which integrated the panelling sides to form the enclosure.

Perhaps the finest example was that of Samuel Johnsons Express No. 1606 of 1893 (Fig. 41) which combined the wheel splasher with the side panelling. The elegant curve on the side panel enhances the highlighted clean flowing lines of the overall engine and tender.

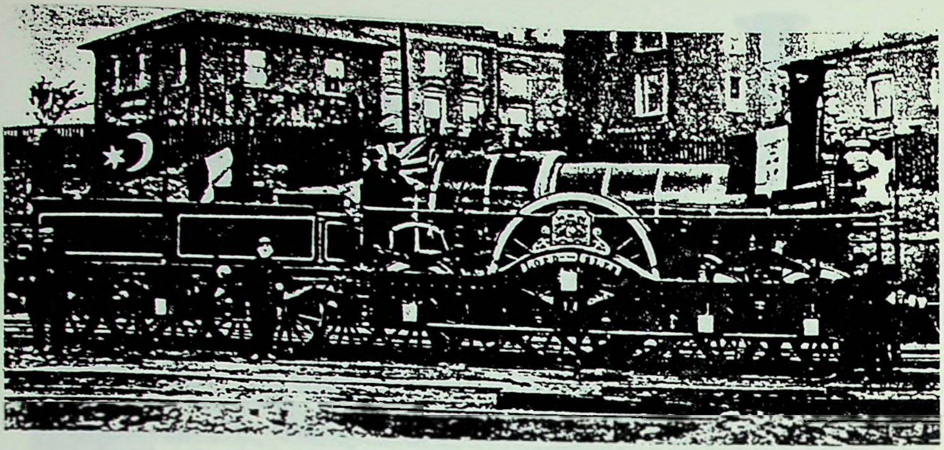
The length of the chimney was reduced gradually up to the year 1920. The top height remained the same, but as the boiler was raised, the distance between it and the bridges was reduced, resulting in a shorter chimney. The chimneys of the 1880's tapered out slightly towards the top and were fitted with a cap. This was sometimes made from polished brass which could not have remained shining once the smokebox had emitted its dark substance. (Fig. 42). These designs were hall markes of engineers William Stroudley Samuel Johnson and Dugald Drummond who greatly influenced the aestetic appeal of locomotives at that time.

William Adams more noted for the development of the four wheeled bogie, introduced what was termed a 'stove pipe' chimney on his locomotives. This had no pretentions other than simplicity and is a distinguishing feature of his engines (Fig. 43).

The firebox and boiler of engines were lagged and enclosed with sheet metal from 1860 onwards. The sheet metal joints were highlighted with distinctive colours which broke up the large area visually, and contributed to the clean smooth lined appearance.

Most locomotives had large broass polished mountings on the boiler which differed only in height. The smokebox doors had reached the uniformity of being circular and hinged on one side. Previous smokebox doors had two horizontal hinges as seen on the design of R. and W. Hawthorn in 1853 (Fig.44) Later a single horizontal hinge was used notably by John Ramsbottom on his D.X. Goods (Fig. 45). The side hinge appears unbalanced and crude in comparison with other exterior details. The weight given to the hinge straps fixed on the outside of the door, is important in distributing the effect (Fig. 46). Shows the imbalance. The hinge design has been improved visually on J.G. Robinsons design of 1908 (Fig. 47).

In 1884 t.W. Worsdell introduced a notable design which had a continuous splasher over the two driving wheels. (Fig. 48). The splasher enclosed the sand container which was not as neatly integrated into other locomotive designs. Steam sanding was used to overcome the wheel slip problem which occurred, especially on single wheel driven engines. The wheel slip occurred on starting from stop, and sand was used as a means of increasing the friction between the wheel and track. The sand was forced by steam, down a pipe in front of the driving wheels, onto the track. The extension of the wheel splasher as in (Fig. 49). was a more general way of integrating the sand box.



(Fig. 35.)

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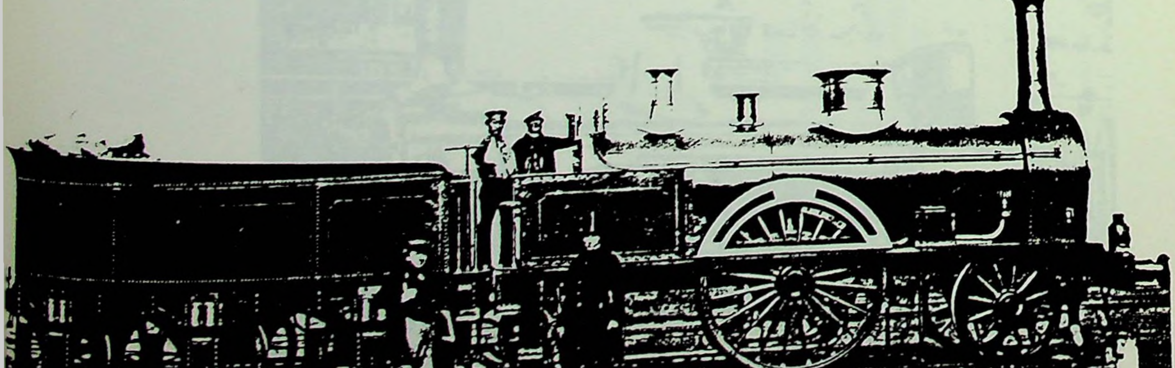

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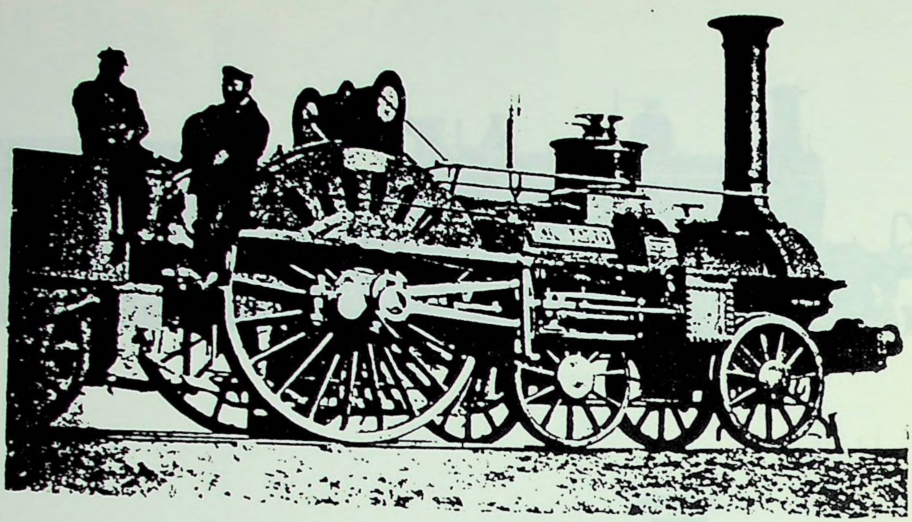

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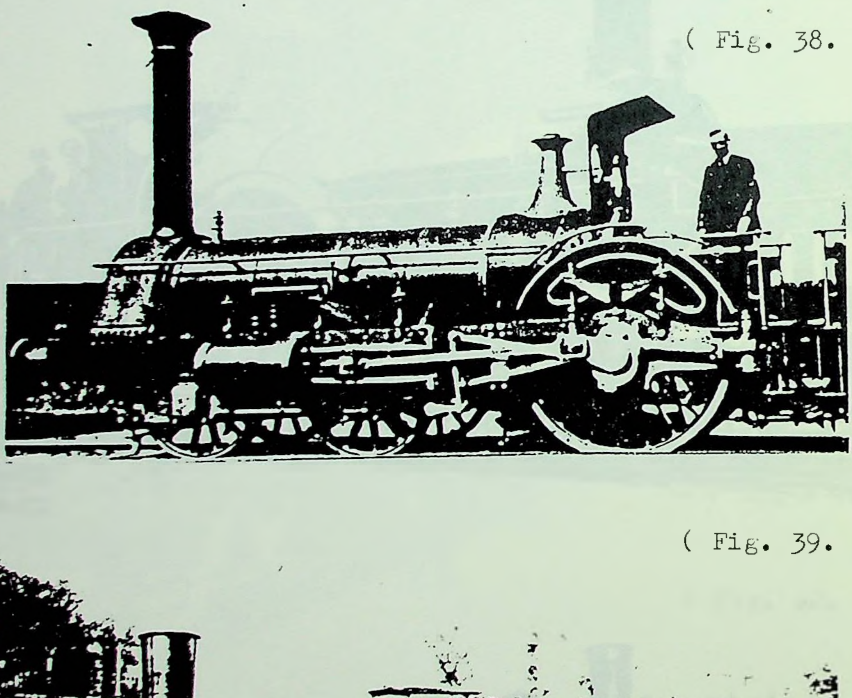

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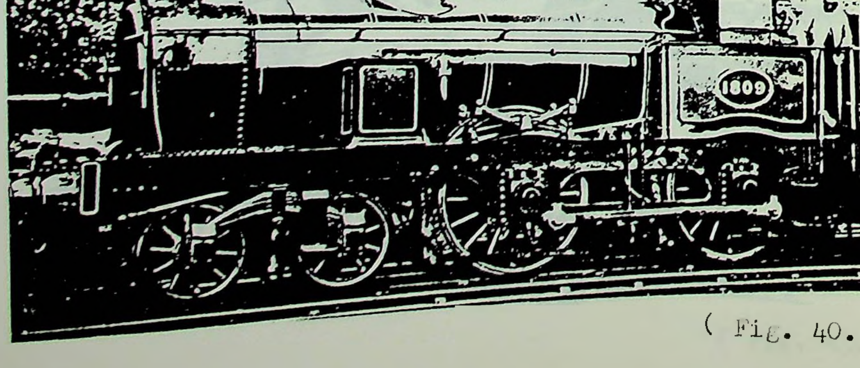

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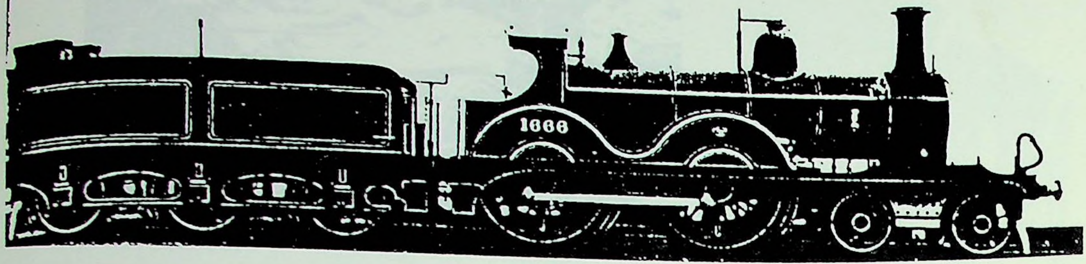

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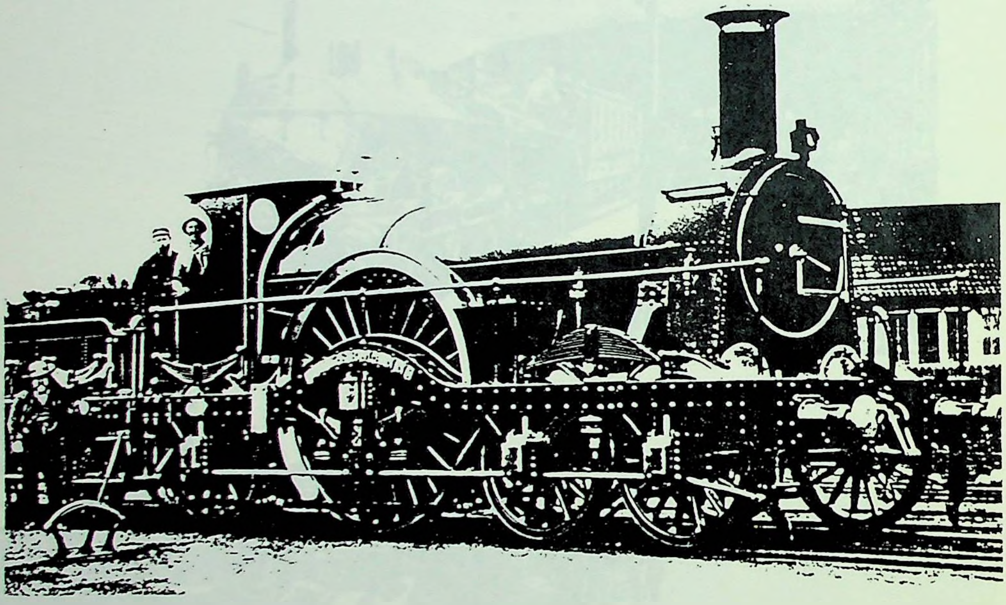

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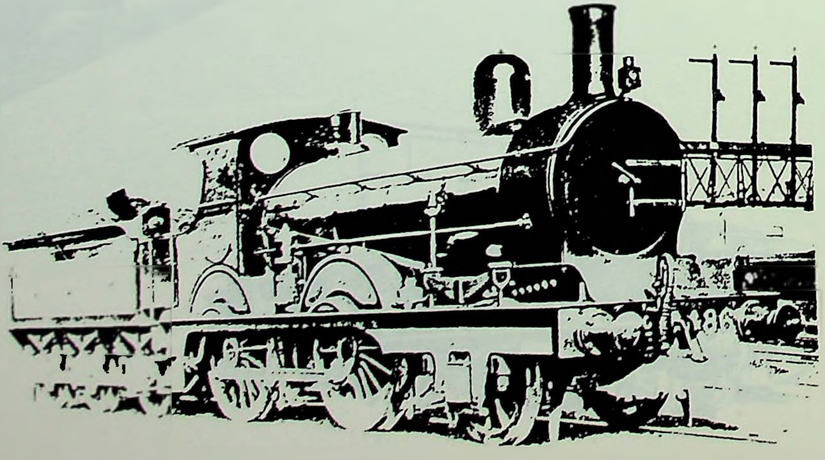

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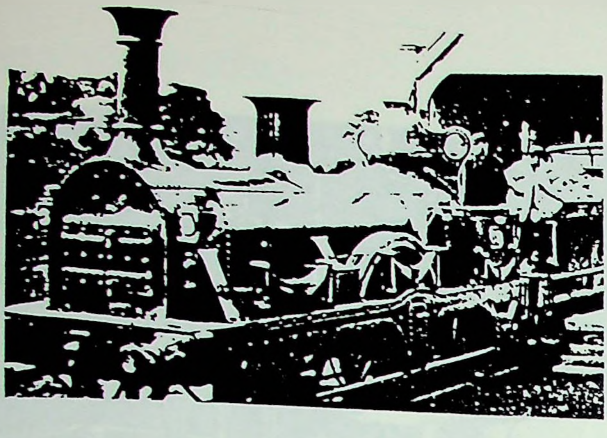

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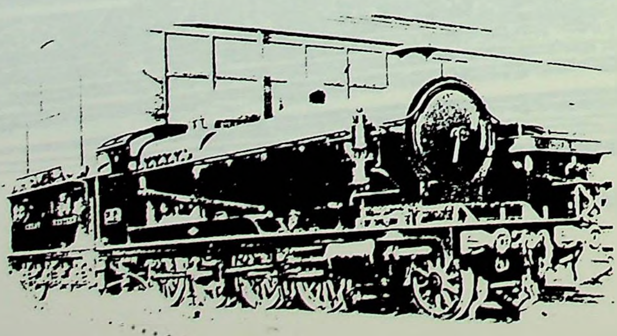

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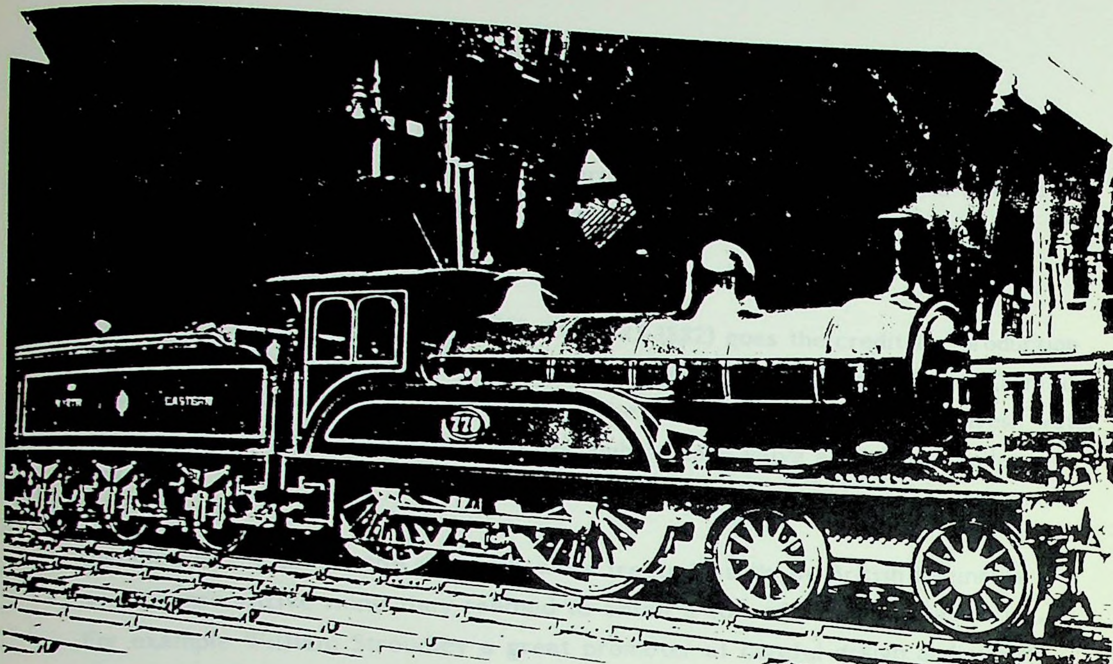

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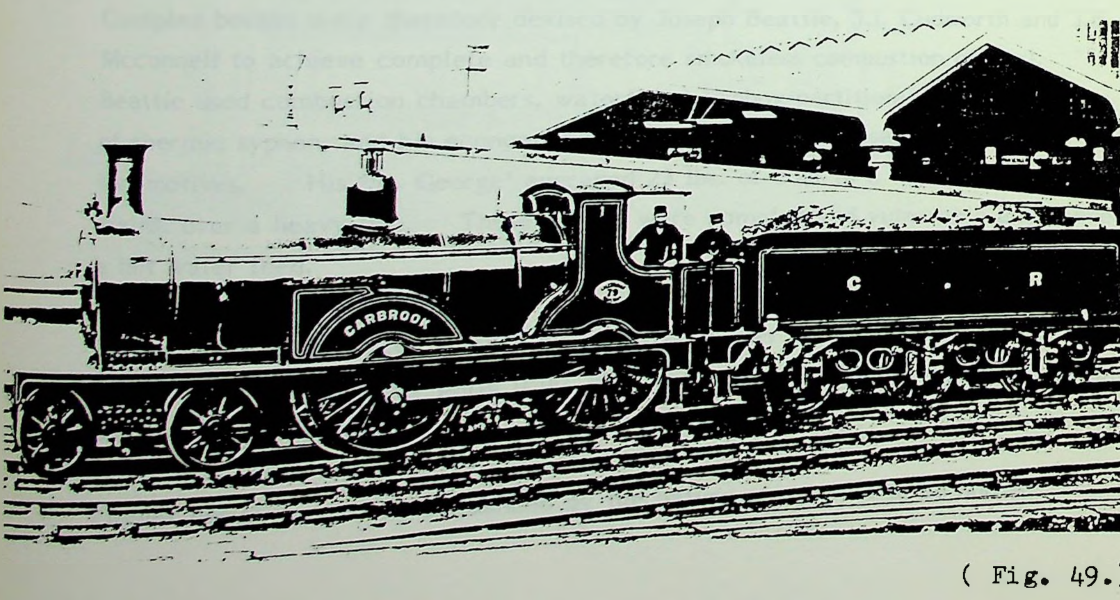


(Fig. 49.)

Boiler and Firebox Design.

The passage of feed water into the boiler under pressure was originally achieved by force-pumps which were worked by a crank or an extension rod. In either case the engine could replenish loss by evapouration only when the wheels were revolving. During idle periods unless spent on a special roller-bed, it was necessary to steam a locomotive backwards and forwards for this purpose alone.

To the French Engineer Henri Gifford (1825-1882) goes the credit for production of the first practical injectors, in which the energy of live steam issued from a jet, draws feed water into the boiler. The steam condensed with the fresh water creating sufficient pressure to pass through a clock-valve against the boiler pressure.

Installed in the 1850's the injectors were treated warily by British Engineers to who's conservative mind they seemed to entail a sort of mechanical cheating. For example William Stroudley a great promoter of careful design and superb workmanship clung to his old force-pumps.

One of the most important aspects of the 1860's was the substitution of coal for coke as fuel. Coke was expensive, but complied with the early leslislation, which stated that locomotives "must effectively consume their own smoke". It provided the only sure way of smoke emission and subsequent prosecution. Complex boilers were therefore devised by Joseph Beattie, J.I. Cudworth and J.E. Mcconnell to achieve complete and therefore smokeless combustion of coal. Beattie used combustion chambers, waterfilled firebox partitions and even a form of thermic syphon, and his economics have never been surpassed by orthodox locomotives. His 'St. George' averaged 23 lbs. of coal to a mile with express trains, over a heavy line. These boilers were complex and vulnerable and needed a hot water feed.

Matthew Kirtley produced a much simpler coal burner firebox by means of a brick arch and a deflector plate (Fig. 50) Though less efficient it was more durable and cheaper to maintain.

Firebox design was solely influenced by the nature of the fuel to be burned.

The Bogie.

The inequalities in the surface of the track and sharp curves were highlighted with the increase in length, weight and speed of locomotives in the 1870's. Efforts had b een made throughout development work to improve the riding qualities, however as the speed increased on passenger trains, safety was given more serious consideration.

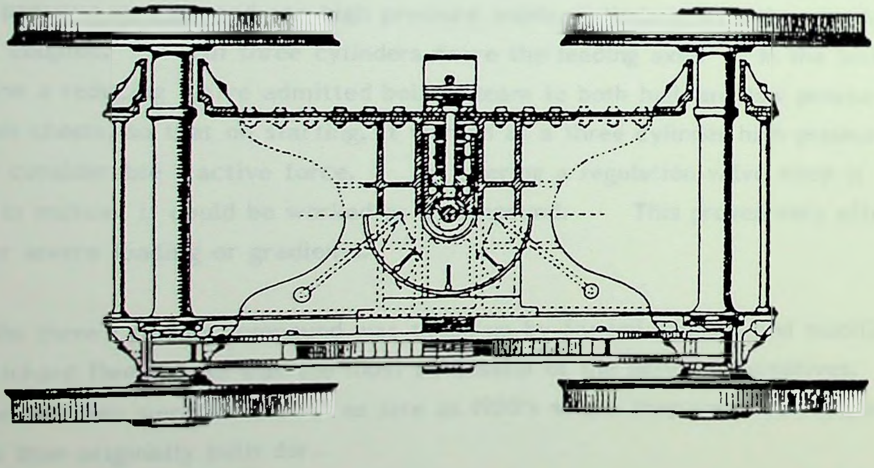
The efforts of Stephenson and Crampton when designing larger locomotives, to improve the riding qualities did'nt suceed. Their designs were restricted by their inability to arrive at a solution to the problem.

A bogie, described as a separate frame containing two carrying axles with wheels of equal diameter, was first introduced by Edward Fletcher in 1864-65) for the North Eastern Railway. This was developed to provide better rounding of the severly curved line between Whitby and Malton. The frame supporting the axle bearings was pivoted at a centre pin, allowing both axles to turn in line with the curved track. This design does not seem to have been used by other railway companies, probably because of its isolated source.

William Adams (1823-1904) patented a four wheel bogie (Fig. 51). and applied it on locomotives he designed for the North London Railway. The wheel base was made long to give steady running and the pivot moved in a transverse slot. The improvement in this bogie was the ability of the independant axles to move laterally. This was achieved by the transverse slot and was controlled by inclined planes or later springs. Thus the four wheels of the bogie followed the curve of the track.

The Adams bogie was considered to be an excellent design and they were used extensively throughout the world. The bogie was instrumental in the development of high speed trains.

Radial trucks and axle boxes provided an alternative but did'nt give as satisfactory results especially at high running speeds.



(Fig. 51.)

Compound Locomotives and Superheating Steam.

The use of compound expansion in steam locomotion was for long a goal of engineers. As early as 1850 John Nicholson of Eastern Counties Railways devised a continuous expansion locomotive with two cylinders, high and low pressure respectively. This differed from the true compound engine of later years, in that the system first admitted steam to the high pressure cylinder only and worked expansively in both.

The object of compounding was to economize on fuel by making the fuller use of a given supply of steam. The most extensive user of its application was Francis Webb.

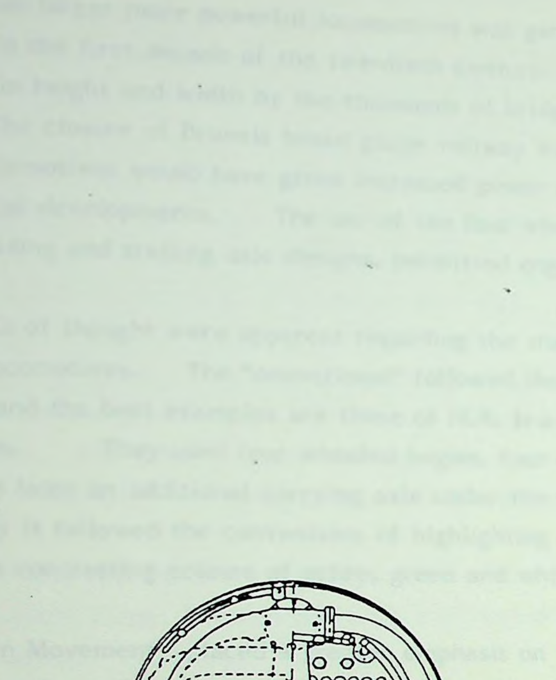
The most familiar Webb compound type had two high pressure cylinders outside, driving a trailing axle and a single low pressure cylinder inside, driving the middle axle, the two pairs of wheels being uncoupled (Fig. 52).

W.H. Smith influenced compound locomotive development with the introduction of a system completely reversing the Webb arrangement in 1898. It had two low pressure outside and one high pressure inside, cylinders, with the wheels four coupled. All three cylinders drove the leading axle. In the Smith engine a reducing valve admitted boiler steam to both high and low pressure steam chests, so that on starting, it worked as a three cylinder high pressure, with considerable tractive force. By altering a regulation valve when it was in motion, it could be worked as a compound. This proved very effective under severe loading or gradients.

Smiths three cylinder compound was taken up by Samuel Johnson and modified by Richard Deeley and was the most successful of the British locomotives. Large numbers were built even as late as 1920's where they undertook heavier loads than originally built for.

The idea of dried steam had long appealed to locmotive men, and as early as 1840 a live steam chamber in the smoke box, with smoke tubes passing through it was fitted by R. and W. Hawthorn. It was not until the end of the century, that Wilhelm Schmidt of Kassel conducted experiments in true superheating which were to influence boiler design during the ensuing half century. The principla was that the steam pipe from the collector in the boiler, passed to a header where live steam was passed through hair pin tubes. Each of these passed into and out from a series of enlarged flues to a second header, from where it passed on to the steam chests.

Its design was conceived in the ninteenth century and its advantage proven in the twentieth. In Britain its application was tardy, where modifications of the Schmidt system were made by Churehwards 'Swindon' superheater, Robinsons superheater, Uries 'Eastleigh' superheater.



(Fig. 52.)

The Modern Aestetic.

The need for larger more powerful locomotives was generally accepted by engineers in the first decade of the twentieth century. The design was restricted in height and width by the thousands of bridges and tunnels already built. The closure of Brunels broad gauge railway was now regretted, as broader locomotives would have given increased power with the improved technological developments. The use of the four wheeled bogie and flexible leading and trailing axle designs, permitted engines to be longer.

Two schools of thought were apparent regarding the shape of the more powerful locomotives. The "coventional" followed the classical style of the 1890's and the best examples are those of H.A. Ivatt, John Aspinall, and J. G. Robinson. They used four wheeled bogies, four coupled large driving wheels, and later an additional carrying axle under the now enlarged firebox. Aestetically it followed the conventions of highlighting curved areas and boiler, with contrasting colours of ochre, green and white.

The 'Modern Movement' placed a greater emphasis on technical innovation than aestetic appeal. The form resulted more from the attention to functionalism than a deliberate visual creation. It was as a result of the technical innovation that the modern locomotive evolved. The quality of finish and workmanship was equal to that of conventional engines, and this was important in their eventual acceptance. The breakaway from conventional aestetics was initiated by Jackson Churchward with 'The Great Bear' of 1908 (Fig. 53). This was the first engine of this wheel combination 4-6-2 to run on the English railways. They are similar in size and combination to the six coupled bogie type first introduced on the Chicago Milwavkee Railway in 1889. Generally referred to as 'The Pacific Type' it was later to become the basis for Nigel Gresley's excellent designs.

When Jackson Churchward first introduced his 'Great Bear' it was received more with astonishment than actual contempt. The overall composition was one of few lines and simple shapes. The principal features were the domelss boiler, flat topped firebox, medium high running board and small wheel splashers. The previoulsy extravagant use of outlining was replaced with unbroken areas of similar colour. The engine was ahead of its time in concept and remained the only one in operation in England for fourteen years.

Richard Maunsell continued this trend when he built tapered boiler engines with a 'Mogul' wheel formation. The 'Mogul' were imported into England during a builders strike, and consisted of two small leading wheels.

Nigel Aresley initiated his building of large locomotives with a three cylinder 'Mogul' type in 1920 for the Great Northern Railway (Fig. 54). The six foot diameter boiler was the largest built at that time and was connected by outside steam pipes to the cylinders. This when combined with the high running board gave it a 'modern' appearance.

In America the 'Pacific Type' had undergone some significant testing and research during the years (1910 - 1916) The results achieved on the Pennsylvania Rairoad with the K4 type were published whichpersuaded Gresley to further develop this type of locomotive which first appeared in 1922.

The 1923 amalgamation of railway companies resulted in just four major companies remaining, which had considerable effects upon the course of locomotive development. Previously numerous designs were produced by individual engineers, but now it remained in the hands of just four individuals.

These were Maunsell (Southern Railway), Gresley (London and North Eastern Railway) Collett (Great Western Railway), and Hughes (London Midland and Scottish Railway).

Steam Turbine Locomotives.

When electric locomotives had proved practical there were attempts to produce engines which could effectively carry their own power station. When initially conceived by the Heilmann Company in France it had a reciprocating steam engine. In Scotland John Ramsey used a steam turbine to achieve the same result but both engines were very cumbersome though original.

The steam turbine engine which was self condensing, was incorporated into a locomotive first by Reed and Macleod and was exhibited at the British Empire Exhibition in 1924. S.N. Ljungstrom in Sweden made further experiments with the condensing turbine which promised savings of 7 - 15 per cent on coal compared with recriprocating engines. Beyer, Peacock, and Company who have been recognised as the finest builders of steam locomotives built a large type which underwent trials on the Lond and Midland Railway in 1930. the condensor which was essential for steam navagation proved very troublesome for land transport and later eingines were non condensing.

The steam turbine required less maintenance because of the simplicity of moving parts resulting from the elimination of the conventional cylinders and valve gear. the turbine itself impoarted a continuous rotary motion to the road wheels, which eliminated the 'hammer blow' associated with reciprocating parts. This also produced a continuous exhaust at the blastpipe, resulting in less mechanical strain on the boiler, and firebox, than had been experienced with the rythmic suction effect of conventional exhaust beats.

Sir William Stanier a noted exponent of quality designs of the conventional type in the 1920's and 30's built a 'turbomotive' in 1934 which operated very successfully. (Fig. 55). The turbine is seen as an upward extension of the running board which covering the full length of the engine. The reverse turbine which is smaller is positioned on the opposite side. It ran until 1950 when the cost of replacing the turbine was considered excessive and it was rebuilt as a conventional type.

STREAMLINE.

Deliberate attempts to reduce the resistant to motion through air by fitting fairings date back well into the ninteenth century. The largest such experiment was on the P.L.M. in France. There many express locomotives were filled with fairings in the 1890's in an attempt to reduce the effects of the "Minstrel" on trains running along the Rhone Valley. The fairings had sharp leading edges like boat hulls, on the mistaken assumption that the form evolved over centuries for low drag on water, would also be correct for moving through air. No improvement was found on the running of trains and some crews thought the fairings made matters worst. On later P.L.M. engines only the wedge fronted cab was perpetuated which helped deflect smoke out of the drivers line of sight and reflections on the glass at night were reduced.

the rapid development of powerful aircraft led to the discovery that the lowest drag in air was achieved with fish like forms, having a smooth rounded edge and sharp trailing edge. In a wind/tunnell it could be seen that the air flowed around such bodies with least turbulence, which could be detected by looking at lines of fine streams of chemical smoke injected into the air. Hence the term streamlined was coined to describe a shape developed by this method.

Nigel Gresley who kept himself well informed of developments in other countries and was a close friend of French locomotive engineer Andre Chapelan, introduced into England the first streamlined locomotive in 1929. The express locomotive No. 10 000 (Fig. 56). was a radical change in form from existing designs. It had a smooth steel casing fitting closely over the actual boiler. The casing finished with a sharp curve over the top of the wheels allowing easy access for maintenance. Because of the height of the boiler there was no room within the permitted height for an extending chimney above the casing. To ensure that the smoke would not be drawn down over the cab, an 'aerodynamlc screening' was used. This was a convex curved form rising from the front buffers to the chimney. It was enclosed by the side sheets and left open at the top permitting the rising air to pass up in front of the chimney, and left the smoke clear of the following cab.

The boiler was a water-tube marine type which had a working pressure of 450 lb per square inch which was twice that used on Pacific types. It was powered by four compound cylinders which were operated by Wolschaerts valve gears. As was to be expected with such an original design there were many teething problems. In trials carried out between Leeds and Hull impressive results were achieved. The economics in fuel consumption resulting from high working pressure and compound expansion were far outweighed by the difficulties created in its individuality in design. It appears that unfamiliarity with its operation was a major reason for its rebuilding in conventional form in 1937.

In 1934. the most powerful and first eight coupled express passenger locomotive was built by Gresley. The 'Cock of the North ' (fig. 57) was designed to haul 550 ton trains at a high average speed over the heavily graded route between Edinbur and Aberdeen. The steam was distributed to three 21 inch x 26 inch' cylinders by rotary cam poppet valve gear. All six were operated by two separate cam boxes, one on each side of the locomotive. The locomotive hauled its 550 ton load between Aberdeen and Montrose, 8 minutes faster than the Pacific type with a 440 ton load.

The exterior of the engine was more conventional than the 10000 but included a similar 'aerodynamic screening' on the front. The boiler casing was made in an elliptical cross section to conceal the pumps and associated pipework.

In America in the 1930's public interest had been aroused by Streamlining and Railway companies raced to produce such designs. The competitiveness was further fused by the developments being made with diesel locomotives, which were presented as a new era in stainless steel streamlined form. Steam locomotive companies employed industrail designers to promote their image and the result was creative streamlined forms. Prominent among designers were Otto Kuhler, Norman Bel Geddes, Henry Dreyfuss, and Raymond Loewy, who's creations were to influence British Streamlined design.

The proposed introduction of the German Built diesel railcars used on the 'Flying Hamburg' was withdrawn after trails showed that the unstreamlined 'Papyrus' could cover the London-Newcastle route in 38 minutes less. However, it was felt that economy in working and a greater margin of power would result if both the locomotives and train were streamlined. How much of this is direct economics or influenced desire for an improved aestetic appeal is difficult to access. The occasion of the launch of the new look engines would seem to indicate that appearance was of the highest order.

The streamlined A4 Pacifics were to enter service for the inauguration of the Silver Jubilee on the 30th September, 1935. The form decided upon by Nigel Gresley and Oliver Bollied was a blunt wedge shape without side sheets, which blended into the ellipical shaped boiler cladding on top. The chimney is placed on this curve to avail of the rising air which lifts the smoke. The vertical side cladding is flared out above the wheels to meet a valance of aerofoil shape. The top of this valance is flat which affords it a much safer foothold for maintenance and cleaning. The casing is designed with a single curvature almost throughout for assembly from sheets of steal which could be folded with existing machinery.'

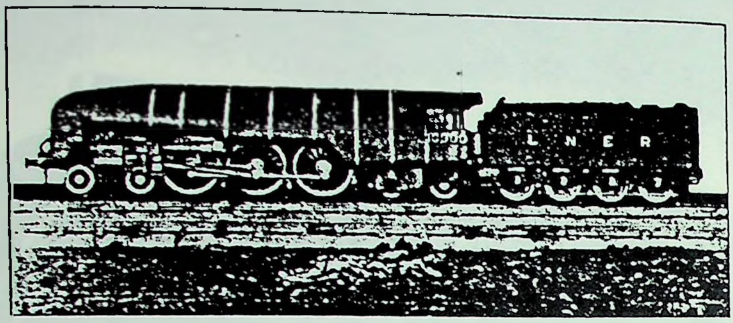
The wedge shape was the aerodynamically crucial part of the design, which was based upon the front of a petrol rail car designed by Ettore Bugatti for the P.L.M. in France in 1934. This shape had been evolved by Bugatti after extensive trial and error in reducing petrol consumption. The drag reduction in Gresleys locomotive was offset by difficulties in accessability for maintenance.

A number of modifications were also made to the interior of the engine, particularly the size, shape and surface finish of the steam and exhaust passages. The stopping distance was also reduced by increasing the brake power from 66 per cent to 93 per cent of adhesive weight.

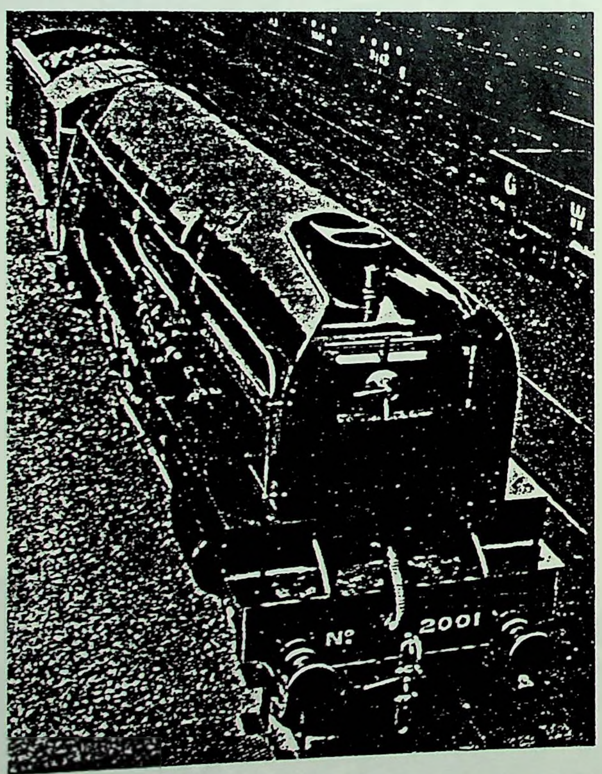
The colour scheme was original and departed from British tradition but was decided upon because of a royal jubilee. The superstructure was pale grey with mid grey on the aerofoil valances and charcoal grey on the wedge shaped front. Four locomotives of this colour were made and were given quite appropriate 'silver' names. These excellent locomotives showed that streamlining was effective in reducing the running cost in terms of spent energy. The 'Silver Jubilee' achieved an average of 100 miles per hour on a trial 43 miles run.

A later model named the 'Mallard' (Fig. 58) holds the world speed record for a steam locomotive at 126 miles per hour which was set on the 3rd July, 1938. It exemplifies the finest in British locomotive design, combining balance, individuality, beauty, and performance into a form that had been evolving over the previous 135 years.

In 1937 streamlining spread to the Anglo-Scottish services, when the L.M.S. built five Pacifics based on Staniers of 1933 with modifications and a streamlined exterior. Their design was in response to Gresleys A4's and timed to coincide with the coronation of George VI.(Fig. 59) shows the streamlines diverging from a point on the centre of the front, in a sweeping curve and travelling along the side of the complete train in parallel. This shows a more pronounced American influence which has been used with care. These Pacifics don't have the same degree of refinement as the 'Mallard' and tend to appear as an oversized shell.



(Fig. 56.)



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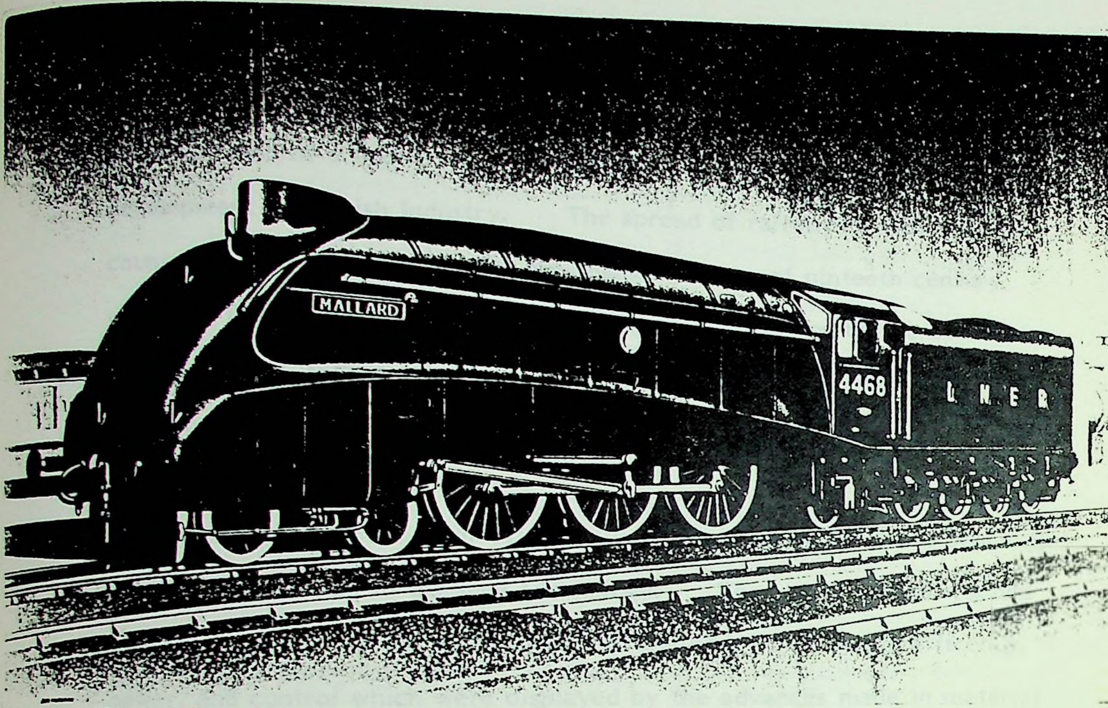
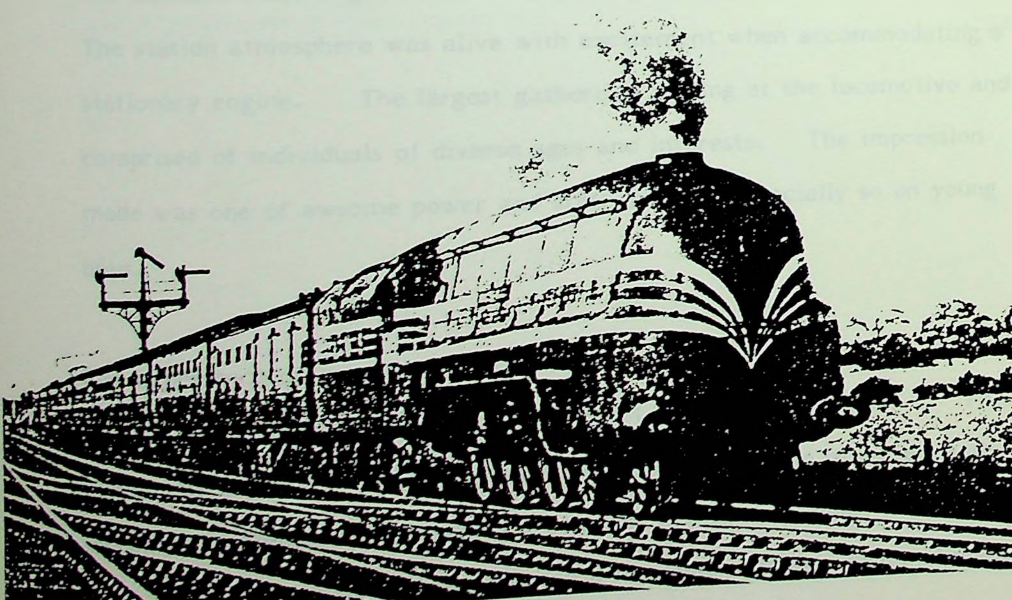


(Fig. 58.)



(Fig. 59.)

CONCLUSION

The British Railways 'Last day of Steam' on August 11th 1968 marked the tragic end of a highly innovative and influencial factor in the development of British Industry. The spread of railways across the country had been responsible for the transformation of ninteeth century work and life. The establishment of new industries for the construction of locomotives, rolling stock, and diverse apparatus, planted the seeds that flourished in the early twentieth century.

The development of the locomotive provides a key example of the evolution of design in relation to the new technology. The evolution had reached a form, derived from the most successful methods of achieving efficency, power, and control which were displayed by the advances made in material shaping. The steam locomotive was individual, characterised by the ingredients which gave it life, coke, air, fire, smoke, water and steam.

The acclaim these engines received by the general public was enormous. The station atmosphere was alive with excitement when accommodating a stationary engine. The largest gatherings milling at the locomotive and comprised of individuals of diverse ages and interests. The impression made was one of awsome power and size, this was especially so on young boys.

The experience of travelling by steam locomotion was stimulating especially in the last decades of running when comfort was at its premium. The movement would begin with the loud thrust of the pistons which gradually increased in frequency generating a sense of excitement about the journey. Once running the rythmic beat created a harmony subconsciously, which made for a relaxing journey.

The effects of the War on locomotive development were compounded by the increased effiency offered by diesel electric and the electric systems. Steam engines continued to be built but an inevitable conclusion was awaiting them, as a rationalisation of lines was introduced. The decree in the British Railways Modernization plan stated 1955 for its last operating year. War years had resulted in engines being abused, which changed their previous association with the public to one of grimy obsolescence.

The result was a rapid importation and deployment of 'new image' engines which lifted the hangover suffered after the war. The application of steam technology would perhaps have been given more serious consideration had the fuel situation been more predictable. Steam locomotives have been preserved by numerous private enthusasists as well as National Museums and are demonstrated on unused tracks on frequent occasions. This serves very well to inform present and future generations of the achievement attained by their designers. The use of steam technology may again have a considerable role to play in transportation should the environment which serves the present system fail.

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