JOSEPH LOCKE 1805–1860

Railway Engineer

Making his home in Honiton, Devon at the latter part of a long and industrious career, Joseph Locke was one of three giants of engineering to whom the beginnings of Britain's railway network can be attributed. His associates were Brunel and Stephenson, so famous now that Locke is sometimes, unfortunately, referred to as the 'forgotten engineer'. His achievements are equally impressive however, particularly as so many were completed during the very early stages of an illustrious career.

Joseph was born on 9th August 1805 at Attercliffe, near Sheffield, Yorkshire, the youngest of four children to William Locke, a colliery manager. He attended Barnsley Grammar School and then at the age of thirteen, presumably because of his father's background, went on to become a pupil of William Stobart, a colliery viewer for two years. The colliery viewer's duties are those of a manager who would be responsible for the day-to-day running of the pit and the hiring and firing of workers.

At the age of eighteen he was articled as a pupil engineer to George Stephenson, the father of Robert Stephenson, at his works in Newcastle and eventually was appointed as one of Stephenson's assistants in the construction of the Stockton and Darlington plus the Liverpool and Manchester Railways. In a letter to Robert Stephenson he once wrote, 'Whilst surveying, what do you think I did? Only what others have done, fell in love with engineering!'.

Such was his interest and enthusiasm in this new manner of transportation that, along with Stephenson, he published, at the age of only twenty four, a pamphlet titled 'Observations on the Comparative Merits of Locomotive and Fixed Engines' which concluded in favour of locomotive engines. The question at the time was whether it was better to have steam locomotives on the rails pulling carriages or to have stationary engines at the track side operating a cable which pulled the carriages rather like the trolley cars' arrangement in San Fransisco today. It would seem that it was this grounding that really inspired him to devote the rest of his life to this new form of transportation.

It was during this part of his career that he was involved in a fatal accident. The grand opening of the Liverpool and Manchester Railway in 1830 was marked by the attendance of Prime Minister the Duke of Wellington and the local MP William Huskisson who had championed the construction of this railway. The Duke and Huskisson were standing by the Duke's carriage from where they had been reviewing the carriages and trains paraded for the opening. As they stood on a railway line to watch, rather a dangerous thing to do even in those days, the steam locomotive Rocket believed to have been driven by Locke, then twenty five years old, approached along the line. The Duke fortunately managed to get clear but, not realising that a steam train cannot stop suddenly, Huskisson was trapped by the leg and this resulted in injuries so severe that he died a short time later. He became, therefore, the first death in the country by this new form of transportation although no blame was put on Locke. The Duke, incidentally, did not travel on a train again until thirteen years later.

Whilst working for George Stephenson on the Liverpool and Manchester railway Locke developed the use of double-headed rails held in chairs mounted on wooden sleepers, and this became the usual form of track on British railways for some time. He also discovered errors in the survey of one of the tunnels, which led to a difference of views with Stephenson who had a tendency to delegate work to inexperienced assistants. It was this disagreement, plus the admiration of the directors of the railway company, that led Locke to branch out on his own. Considering he was only twenty seven years old at the time, this was an incredibly brave stance to take.

Locke's first major project as an independent civil engineer, after the completion of the Liverpool and Manchester railway, was the first trunk railway line called the Grand Junction Railway. At eighty two miles long, it connected Birmingham and the Liverpool and Manchester line via Wolverhampton, Stafford, Crewe and Warrington. He surveyed the land, designed the route and line of the railway, including necessary bridges, viaducts, cuttings and embankmants and then supervised construction. The line was duly opened in 1837 when he was only thirty two years of age.

Locke soon realised the importance of Crewe as an important junction in the railway system and not only designed the railway works, but most of the town itself! This major project comprising one hundred underbridges, five viaducts, two tunnels and two aqueducts was opened for passengers and light goods on 4th July 1837. The sheer scale of the enterprise, designed and supervised by somebody aged only thirty two on its completion, is quite incredible when compared to the amount of planning and construction that goes into building a length of motorway these days. Locke was to help prove that railway travel was not as dangerous as forecast for some harbingers of doom believed that at speeds of over 30 mph milk would turn sour and even people's lungs would collapse!

Sixteen days later the London to Birmingham line opened which meant that this new form of rail transportation linked London, Birmingham, Manchester and Liverpool.

From these auspicious beginnings Locke began to make a name for himself in the country. He was given commissions to design the Sheffield, Ashton-under-Lyne and Manchester railway which was opened in 1845 when he was forty years of age, the Lancaster and Preston Junction Railway, and also the line from Lancaster to Carlisle and onwards to Glasgow and Aberdeen. He developed a reputation for building straight railway lines, avoiding expensive tunneling whenever possible. Although this meant in some cases adopting gradients that were rather uneconomical in terms of running costs, he quickly realised that locomotives could be built to overcome this problem.

Such was his reputation that he received commission for railways in the South of England including the London to Southampton line which included several bridges over the Thames. One, the Barnes Bridge built in 1849, is now famous as one of the landmarks in the closing stages of the Oxford and Cambridge University Boat Race held each year.

Because of his achievements he became closely acquainted with both Robert Stephenson and Isambard Kingdom Brunel and, with them, also associated with the Institution of Civil Engineers.

Not content to work just in Britain, Locke then proceeded to set his sights abroad with project work in Spain, creating the railway line between Barcelona and Mattaro then in Holland with the Dutch-Rhenish railway. He was approached to construct a railway line between Paris and Rouen, and on to Le Havre. This was followed by the construction of a railway line from Nantes to Cherbourg and Caen.

It is interesting to note that the actual construction was performed partly by gangs of British navvies brought over especially for the job. Locke did this for one but nevertheless very important reason. He found that he would not be able to meet the contractual terms for the overall work if he was to use French labour only since they were not skilled in the form of construction planned. British workmen however had had a number of years experience in railway construction, particularly in the use of the then modern equipment designed specially for this type of work. Needless to say, it did cause some comment in the areas where railway construction was undertaken due to the high wages then paid to British workers compared to French labourers. However, it was soon realised that the British navvies were also used to being well fed and consequently produced a far better output than their French counterparts. The upshot was that these benefits were realised and the French worker began to enjoy an improved lifestyle. He also noted that the French utilised female labour in the operation of their railways, such as opening and shutting level crossings and in the manning of country railway stations. A practice which, he commented, would be thought questionable in Britain. How times have changed!

Locke also found that in creating a new railway system in France, the French type of locomotive was inferior to its British counterpart. He saw the need to build not only new locomotives to a better standard, but also that these locomotives would need to be repaired. Consequently he arranged for the establishment of new workshops at Rouen, which became the main supplier of engines, wagons, and carriages for most of the railway companies in France. For his work in France he was awarded the Grand Cross of the Legion d'Honneur by King Louis Phillipe and was created an Officer of the Order by Emperor Napoleon III although regretably, he was never publicly honoured in Britain.

When he was forty two years old he bought the manor of Honiton, and became Member of Parliament for the town. Although he did not make a great name for himself whilst in the House of Commons, he used his experience for technical matters when these arose in the House and at these times he was listened to as one who had particular knowledge of his subject. He also served as a Select Committee Member. He had already become a member of the Institution of Civil Engineers when he was twenty five years old and such was his renown for the work he had undertaken that he was elected to the position of President of that Institution at fifty three years of age.

The last work that he was responsible for was a long cherished project of the extension of the railway to Exeter. However, he never saw the completion of this project because, tragically, he died suddenly in September 1860. Whilst on a shooting holiday in Scotland he suffered a severe infection of the leg, which he had injured previously whilst working in France. His wife Phoebe dedicated Locke Park in Barnsley to his memory and the estate features both a statue and the Locke Tower.

There is no doubt that he possesed extraordinary driving force and foresight. He was responsible for the construction of a network of railway lines in Britain and also on the continent, especially in France, which are still the basis of the railway system today. It would seem that he had a particular quality of mind that gained the confidence of capitalists, so important in the financing of railways at that time. He was also renowned for his ability to complete his railway lines not only on time but also within budget, something today that civil engineers still strive to do, but sometimes find difficult for very many reasons.

It is a strange quirk of fate that Joseph Locke was born within two years of both Robert Stephenson and Isambard Kingdom Brunel and all three died within two years of each other. As The Times printed on his death, 'He may be said to have completed the triumvirate of the engineering world'.

J D Sly

WILLIAM FROUDE 1810–1879

Engineer and Mathematician

Students of hydraulics will be familiar with the use of the Froude number in scale modelling. Even in Devon, however, few are probably aware that its originator, William Froude, was born in the county and spent most of his professional life working there. His great achievement, demonstrating that scale models could be used to estimate the power required to propel ships of different hull shape, resulted from trials undertaken on the River Dart and in a tank adjoining his house in Torquay. Having graduated from Oxford with first class honours in mathematics, he was one of the first to conceive engineering problems in mathematical terms.

William Froude was born at Dartington Vicarage, Totnes in 1810, the son of the Venerable Robert Froude, Archdeacon of Totnes. The Vicarage is now part of the Schumacher College and one of the rooms there is named in his honour. He started his schooling in Buckfastleigh, later going on to Westminster School in London and subsequently to Oriel College, Oxford.

At Oxford Froude's tutors were his elder brother, Hurrell, and John Newman, then a leader of the high-church Oxford Movement, and later to become a cardinal in the Roman Catholic Church. While at Oxford, Froude had also been a follower of the Oxford Movement but, unlike Newman, his views became more liberal and free-thinking in later life.

He and Newman remained friends, however, and corresponded on philosophical matters, such as the nature of proof in science and religion, Froude holding that it was 'his sacred duty to doubt'.

After graduating from Oxford, Froude started his engineering career in 1833 as a pupil of the engineer William Palmer, working on a survey for the South Eastern Railway in Kent. In 1837 he joined the staff of I K Brunel, of Great Western Railway fame, who was to have a major influence on his outlook on life. He was appointed as an assistant supervising the construction of the southern section of the Bristol to Exeter line, based in Cullompton. He must have demonstrated his abilities early, for, in 1842, when work on the line was proceeding badly and other members of the team were sacked, Froude was left in sole charge of the project. Even though Froude had pointed out discrepancies in Brunel's original survey for the line, Brunel clearly had confidence in his young assistant.

While working on the line, Froude used his mathematical skills on the design of two skew bridges, with taper bricks shaped to form the correct spiral courses, as well as formulating transition curves to reduce the sideways force on trains entering bends on the line. During this time he also worked on surveys for the West Somerset and Dorset Railway and for a line in north Devon which failed to get parliamentary approval.

In 1839 Froude married Catherine Holdsworth, daughter of the Governor of Dartmouth Castle and an MP. They had five children, three boys and two girls. Sometime after 1845 Catherine and the children followed Newman into the Catholic Church, unlike Froude himself. Edmund, the eldest boy, attended a school run by Newman and at one time wanted to become a priest. However, he was later persuaded by Newman to follow in his father's footsteps in the study of hydrodynamics.

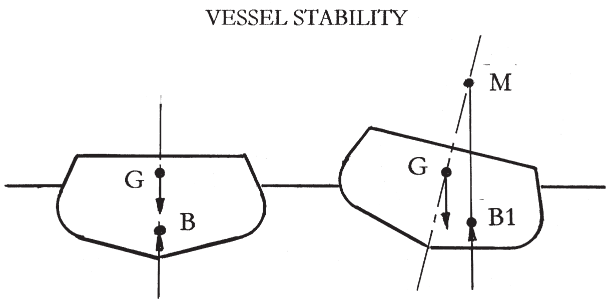
Froude's career as a railway engineer was short-lived, for in 1846 he 'retired' and returned to Dartington to help his ailing father manage the family affairs. The Archdeacon was a landowner of considerable standing in the district. Froude's mother, Margaret (nee Spedding) had died in 1821. His family duties were not onerous, leaving him time to pursue other interests and exercise his engineering talent. He was appointed a harbour commissioner for Dartmouth and designed sea defences there which are still giving service today. He also invented a 'pig' or scraper to clear corrosion from Torquay's water mains, thereby improving the town's supply. He took an interest in agricultural matters and designed dynamometers to measure the work exerted by horses pulling agricultural machinery. He also designed a cow-resistant fence post!

The friendship established between Froude and Brunel whilst Froude was working on the Bristol to Exeter railway continued after his 'retirement', Brunel seeking his advice on a number of occasions. Froude designed an improved seal for the tubes on the South Devon Atmospheric Railway between Exeter and Newton Abbot, but, although this was partially successful, it was not sufficient to prevent the system of atmospheric propulsion being abandoned.

In 1856 Brunel asked Froude to make a study of the rolling of ships in waves, particularly with reference to the stability of the Great Eastern which, when launched early in 1858, did indeed roll badly in heavy seas. He undertook small-scale model tests and developed a mathematical analysis of the problem but, lacking today's computers, this proved impractical to use. His results were presented in a paper to the Royal Institution of Naval Architects in 1861, in which he showed that rolling could be reduced by adopting a small metacentric height , provided this was consistent with safety. Metacentric Height is defined as the distance from the centre of gravity measured along a line perpendicular to the deck to the point where it is intersected by a vertical line from the centre of buoyancy. This is for a non-listing vessel when rolling.

The Admiralty became interested; further work was carried out, including full-scale trials, leading to improvements in the design of HM ships.

Whether at the behest of Brunel or for his own interest, Froude's first experiments with model boats had been made on Lake Bassenthwaite in the early 1850's to investigate the relation between hull shape and propeller action. He was a keen sailor and, in about 1860, wishing to buy a new yacht of improved design, he carried out a further series of model trials on the River Dart. The



G is the Centre of Gravity of the vessel. B is the Centre of Gravity of the water displaced by the vessel - the Centre of Buoyancy. The position of B changes when the vessel rolls because the 'shape' of the displaced water alters. If the buoyancy 'upthrust' through B tends to rotate the vessel to its original upright position, it is stable and the metacentric height G to M is termed positive. If the conditions are such that M is below G the vessel is unstable and the metacentric height is termed negative.

first model known as Raven was built with fine lines, while a second, Swan, had a more rounded hull shape. He built three models of each craft at different scales, 3, 6 and 12 feet (0.9, 1.8 and 3.7 metres) in length, which were towed behind a steam launch owned by his friend, the Devon-born and mathematically inclined engineer, George Bidder. The test showed that the fine-lined Raven gave least resistance at low speeds and the Swan at higher speeds.

Accepted wisdom at the time said that it was not possible to predict full-scale performance by testing models. But Froude was able to show that, if the models were run at speeds in proportion to the square root of their length, then the resistance per unit displacement would be the same, a result that became known as Froude's Law of Comparison..

The term (V x V)/(g x L) where V is velocity, L length and g the acceleration due to gravity, became known as the Froude Number and should be the same in model and prototype.

He reported his results in a paper to the British Association in

1867 and these were later validated by a full-scale trial in 1871 during which the sloop, HMS Greyhound, was towed at different speeds and the resistance measured.

After the death of his father in 1859 Froude moved from the Dartington Rectory where he had been living since his 'retirement', to a rented house in Paignton. There he constructed a tank in the roof to carry out smaller scale trials complementing those on the River Dart. Later, in 1867, he moved to a newly-built house, Chelston Cross (now the Manor House Hotel) in Torquay, which included a small covered tank for model tests and an adjoining workshop.

Despite scepticism in the Admiralty over Froude's claims, E J Reed, the Navy's Chief Constructor, was impressed by his results and, while visiting Froude in 1868 to examine and discuss his work, suggested that he should approach the Admiralty for financial support for a large tank where tests could be carried out under controlled conditions, not possible on the open water of the River Dart. Froude followed up this suggestion and with the help of I K Brunel's son, Henry, prepared a proposal which was submitted to the Admiralty in December of that year. Froude asked for £1,000 to build and equip the tank plus a further £1,000 to cover running costs over two years. Froude offered his own services free, but his son, Edmund, was to receive a salary of £150 per year. Reed's memo to their Lordships of the Admiralty recommending acceptance of the proposal is held in the Public Records Office. There was some bureaucratic delay, which irritated Froude and Henry, but the proposal was accepted and provision for the necessary funds was included in the government Estimates for 1870.

The tank, 270 feet. long, 38 feet wide and 10 feet deep (82.3, 11.6 and 3.0 metres) was constructed by a local builder on land leased on the other side of the road from Chelston Cross, Froude's home. An overhead rail track with a gauge of 3 feet 3 inches (1.0 metre) was supported from the roof beams of the enclosing building, along which a carriage towing the models was pulled by an endless rope operated by a specially-designed steam engine and governor. There was also a brick boilerhouse and workshop. Froude's earlier models had been made from tinplate, but this had proved difficult to form into the required shape. For the new set up, after considering alternatives such as timber, hard wax was adopted as the best option, and a special cutting machine devised to shape the models. After some preliminary calibration trials, the tank was formally commissioned in May 1872.

Early runs were made on models of HMS Greyhound on which full-scale trials had been carried out the previous year. These tests finally confirmed that models could be used to predict the power required to propel full-sized vessels. Henry Brunel helped Froude with the full-scale tests on HMS Greyhound and later went on to design much of the hydraulic machinery for the Tower Bridge, London,

Since his father's death in 1859, Henry Brunel had looked to Froude for guidance regarding his future career and was a frequent visitor to Chelston Cross. Indeed, he began to show tender feelings towards Froude's daughter Eliza. Mrs Brunel, however was unable to countenance the idea of her son marrying a Catholic and quickly put a stop to the budding romance.

In 1873 Froude again turned his attention to the problems of hull shape and propeller design. Tests were carried out on propellers both on their own in otherwise still water and in the disturbed flow behind a ship. He designed a special dynamometer with a chart recorder for use in these tests. This continued to give service until the 1930s. Other tests towing long planks up to 50 feet (15.2 metres) in length along the tank were carried out to find the frictional resistance of different hull materials and surface finishes.

The sceptics in the Admiralty were won over by the success of the tests. Froude was appointed to various Admiralty Committees. Many from the scientific world visited Torquay to see the new tank for themselves. Others came from Russia, the continent of Europe and America.

Froude had been elected a Member of the Institution of Civil Engineers in 1846, of the Institution of Mechanical Engineers in 1852 and of the Royal Institution of Naval Architects in 1860. In 1870, in recognition of his work on the rolling of ships, he had been elected a Fellow of the Royal Society, also receiving an honorary LLD degree from Glasgow University in the same year.

However, Froude's period of acclaim did not last long. Catherine, his wife died, in 1878. Already tired from overwork, this event added to his distress. He accepted the offer of a voyage to South Africa aboard the cruiser HMS Boadicea, which he hoped would be restful, as well as giving him the opportunity to write a paper on the soaring of birds, a subject which he and Henry Brunel had often discussed with the possibilities of human flight in mind.

Tragically, soon after his arrival in South Africa, he contracted dysentery and died shortly afterwards. He was buried in Simonstown with full military honours. The headstone on his grave can still be seen. It is inscribed:

William Froude, Civil Engineer,
FRS LLD of Devonshire, England.
Died at Admiralty House 4 May 1879.
In recognition of the great services which he had
rendered to the Navy.
His remains were interred here by the officers and men of
Her Majesty's ships then in this port

After Froude's death, direction of the testing facility at Chelston Cross was taken over by his son, Edmund. Many reports were produced covering subjects from surface friction to screw size. In 1886 the lease on the site at Chelson Cross ran out. The operation was then transferred to Haslar, Gosport, where a larger tank was built. Edmund remained director until his retirement in 1919.

M C D La Touche

PETER JOHN MARGARY 1820–1896

Civil Engineer

The railway network in the South West of England, much of which is on difficult challenging terrain, owes its existence to the sustained conscientious efforts of Peter John Margary, an engineer highly regarded by all who worked with him.

He was born on 2 June 1820 in Kensington, London, and commenced his engineering career when he was eighteen years old by becoming articled to William Gravatt, who at that time, was chief assistant to Isambard Kingdom Brunel on the Bristol and Exeter Railway. These works had just started and after the expiration of his articles, Margary was appointed as assistant to William Froude, who had succeeded Gravatt having charge of a portion of the Bristol and Exeter Railway.

On the commencement of the South Devon Railway Margary was sent to Devon and given charge of the portion of these works from Exeter to Powderham. Arrival of some two thousand navvies to work in the area did create law-and-order problems on a scale not experienced in this part of the country but no really serious crimes occurred.

Margary assisted Brunel in carrying out the atmospheric system of traction, being placed in charge of the construction of the Engine Houses. This atmospheric system of traction worked in the following manner. A continuous pipe about 0.4 metre in diameter was installed between the rails and contained a close-fitting piston free to slide along the pipe. A narrow longitudinal slot, covered by a leather flap, ran the full length of the pipe and a vertical arm, fixed to the piston, protruded through it. When the piston moved along the pipe, the flap was lifted by the front of the arm then closed behind it, keeping the pipe sealed. The arm could be attached to the front train carriage.

The Atmospheric Engine Houses for which Margary was responsible contained very large pumps which removed air from the sealed pipe ahead of the piston, creating a partial vacuum. Atmospheric pressure on the other side of the piston then forced it along the pipe, pulling the train carriages with it. This system of traction claimed many advantages over conventional steam locomotives – higher speeds, greater safety, improved travelling conditions for passengers and the ability to operate more trains at very little extra cost. Steeper gradients could be climbed thus avoiding longer more level routes. However. it was used only for a brief period on the section between Exeter and Newton Abbot due to operational problems such as the deterioration of the flap material and difficulties in communication from trains to Engine Houses. One of Maragry's buildings stands today at Starcross.

Many engineering difficulties were encountered during the construction of the South Devon Railway, which in many places was under the cliffs and close to the coastline with repeated breaches and damage being caused by ravages of the sea. It is interesting to note that in a report to the Directors of the South Devon Railway upon a serious breach and slip which had occurred at a point on the line a short distance west of Dawlish, Brunel said:

> 'I cannot conclude my report on this occasion without referring to the skill and untiring energy displayed by your engineer, Mr Margary, to whose prompt and judicious executions under emergencies involving considerable difficulties the Company and the public are indebted for a great reduction in the inconvenience caused by the accidents which have occurred. In the case of the slip at Breeches Rock particularly, a temporary wall was most skilfully and rapidly constructed, while exposed to the violence of the seas, in a manner which will serve as a most useful example in sea works.'

Difficulties were successfully overcome and on the first day of public operation four thousand tickets were sold at Teignmouth station to passengers, many of whom had never seen a train before!

This part of the line is still in use today despite ongoing problems from sea water storms.

On Brunel's death in 1859 Margary was appointed Chief Engineer of the South Devon Railway and by 1863 had directed the five timber viaducts on the railway be replaced by masonry structures. He carried through Parliament the scheme for the extension of the Tavistock Railway to Launceston despite strenuous opposition, and this was opened in June 1865. Branches to Moretonhampstead were opened a year later and to Ashburton in May 1872; all were designed by Margary.

For many years he had lived with his wife Emma and three daughters in Dawlish. The Engineers Office seems to have been a room in their house but in 1868 he was appointed additionally as Chief Engineer to the Cornwall Railway with its various branches and this necessitated a move of both home and office to Plymouth.

June 1877 saw the branch to St Ives opened, this being the last to be completed with rails at the broad gauge favoured by Brunel. Meanwhile in August 1870 a new outer arm for Torquay harbour was constructed, called Haldon Pier. Financed by the Palk family, whose home was on the Haldon Hill, and designed by the architect J W Rowell work commenced in 1866 with Margary as the resident engineer. The foundations consisted of blocks of concrete, 10 x 4 x 4 feet (3.0 x 1.2 x 1.2 metres) in size, placed using a railway on a staging which was supported by piles driven into the ground. 75 blocks were required to make 6.1 metres of pier, which is 12.2 metres wide at the top with a parapet 2.4 metres wide. The pier is approximately 230 metres long.

With the amalgamation of the South Devon, Cornwall and Great Western Railways Margary was appointed Resident Engineer of the Company's Western Division. This included being in charge of the docks at Plymouth, where between 1878 and 1881, he carried out the construction of the West Wharf, the deepening of the entrance channel and the extension of the graving dock.

By 1871 Brunel's timber viaducts in Cornwall began to come to the end of their lives. Margary reconstructed fourteen of the thirty four on the Cornwall Railway and seven of the nine on the West Cornwall Railway, presenting a paper describing the work of St Pinnock and Moorswater viaducts to the Institution of Civil Engineers during their 1881-1882 Session. He had been elected an Associate of the Institution on 2 March 1847 and transferred to the class of Member on 31 January 1860.

On his retirement at the end of 1891 some five hundred of his colleagues and assistants presented him with a testimonial of their appreciation of his ability and the respect and kindly feelings they felt for him. Tragically he died of heart failure on 29 August 1896 at the age of seventy six. His peers referred to his 'strong force of character and strict sense of duty, and upright and conscientious conduct on all occassions'. A most remarkable character in every way.

A B George

JOHN HEATHCOAT 1783–1862

Inventor and Entrepreneur

Tiverton, East Devon, was home to John Heathcoat for many years. The solid red brick mill near the banks of the river prominently displays his name high on its front wall, a lasting recognition to the man who earned deep affection from many townspeople.

He was born near Derby in 1783 the youngest of three children whose father, a farmer, tragically lost his sight and was forced to retire from his work. The family moved to Leicestershire where John Heathcoat received a village-school education after which sufficient family savings paid for his apprenticeship to a craftsman making frames for textile machines.

He lived in Kegworth, a town that was on a busy route for travelling merchants and businessmen who talked of the future belonging to those who could invent machines that would use the country's abundant materials, cut waste and save time in manufacture. Heathcoat became fired with enthusiasm instilled in him by a local character Benjamin Wooton who was a land surveyor, astronomer, steeplejack and inspired teacher. A further spur to his ambitions may have occurred when a friend and frequent visitor of his mother's described the fortunes of a London manufacturer of lace-making machinery with the comment 'Well, John – you should do the same . . .' Heathcoat had already wondered if the cottage industry art of making pillow lace by hand could perhaps be accomplished by machine.

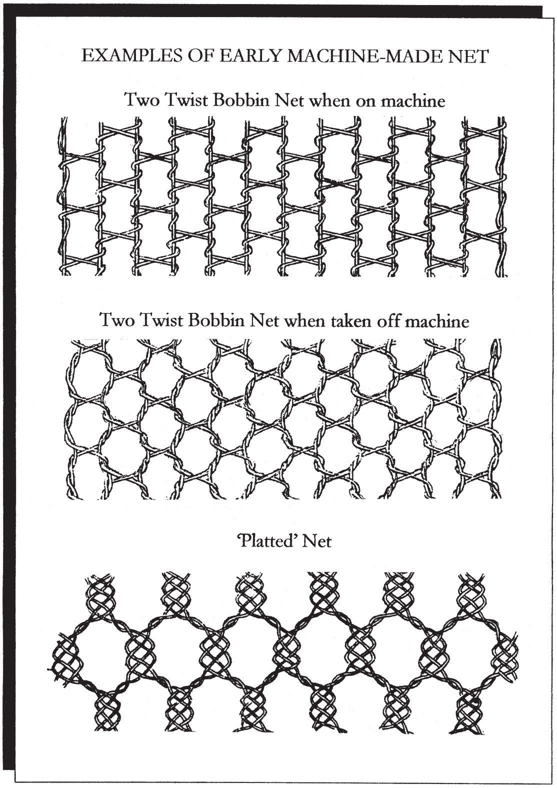
On completion of his apprenticeship he moved to Nottingham to work for another framesmith building knitting machines where his skills soon commanded a high wage. His employer very quickly assessed Heathcoat as 'inventive, persevering, undaunted by difficulty or mistakes, patient, and having great self-confidence'.

Heathcoat had many ideas to improve the machines on which he worked but inventions need financial support plus time and materials for experiments. The scale of this support was beyond the means of his friends, family and workmates so he approached William Jeffrey Lockett, a Derby solicitor, who, impressed with Heathcoat's manner and the drawings that he had produced, agreed to make a large financial investment. The money allowed Heathcoat to purchase the goodwill of his employer. He continued as a master craftsman and worked on his ideas and inventions in all the spare-time he could find. He was now twenty one years of age and had been married for two years.

After four years of trials, experiments and tests Heathcoat finally produced a model of a bobbin net making machine which he then patented. The famous engineer Brunel's view of the design was one of total admiration. Heathcoat had taken the most difficult and beautiful thing a human hand could do and demonstrated it could be accomplished by machinery.

The year of the patent was 1809 and from this date Heathcoat found himself as an industrialist in a business whose purpose was to produce and use the new bobbin net machines in quantity and reap the rewards. He needed working capital and in the quest for a partnership moved to Loughborough and started an association with Charles Lacey who had previously operated in the net trade. With Heathcoat, Lacey became the joint owner of the patent and joint owner of a Loughborough factory in which, by 1816, fifty five frames were operating. Additional financial reserves were needed so Heathcoat assigned to certain selected manufacturers the right to use his patent. The law with regard to patents was quite complex at the time and he became involved in a court case with some other manufacturers, the favourable result of which secured for him total patent rights which would not again be challenged. Heathcoat then located every machine which had been constructed to his model design without his permission and collected substantial fees from the owners of these machines. This provided more working capital for the Loughborough factory.

The years 1811–1812 saw the emergence of a group of machine wreckers who would operate under cover of darkness in bands of fifty armed with hammers and axes. They were termed Luddites after a youth named Ned Ludd who was punished for chronic idleness and redressed his grievance by breaking up two machine frames. The movement was very well organised, its members mostly the victims of unendurable hard working conditions, excessive hours of labour and low wages. They saw the machines as a threat to their jobs and the illustration below gives some



indication of the complexity and ingenuity of the machines of the time.

By 1812 about one thousand hosiery frames had been wrecked in the Midlands and in June 1816 a large group, who were either Luddites or others in the pay of Heathcoat's rivals, broke into his factory and demolished fifty five machine frames, setting fire to the lace and the building with all it contained. Seven of the culprits were caught and hanged but two hundred employees were made jobless. Heathcoat was hit hard, not only financially, but also in his faith of human nature. Later that year, at the age of thirty three, with his business partner John Boden, he moved to Tiverton where he had previously set in motion the purchase of the mill there from the owners Heathfield and Dennis. The six story impressive mill building was well ahead of the general industrial design of the times. The textile machines were later powered by an impressive water wheel 7.6 metres diameter, 6.1 metres long weighing, with the associated machinery, 80 tonnes. It took a year to install, then kept rotating at 3.5 revolutions per minute for three quarters of a century.

Many of his Midland workers carrying their possessions, some with families, walked the two hundred miles across the country to Tiverton for employment. It was here that Heathcoat, with all his practical skills, efficiency and tact, successfully managed to bring together two groups of employees; one from Loughborough trained in many skills and the other local and unfamiliar with the work that would be demanded of them, some not taking kindly to the invasion from the Midlands. It was not long however before Heathcoat was held in esteem and by 1823 was employing about 1,600 people.

To improve profitability Heathcoat embarked on a strategy of diversification and the elimination of 'middlemen' from his business. Most operations were performed at Tiverton including metal working and frame construction in the factory workshop. The foundry was used also to manufacture agricultural implements and even a major brickworks was set up. A new coal gas plant supplied not only lighting for the mill but also the town's street lamps. He invested in land and property, purchasing a wool mill at Pilton, Barnstaple, converting it into a bobbin net factory.

One of his ventures was the invention of equipment which would draw off silk strands from cocoons and then twisting the strands into a thread. Given that just one cocoon could have up to 1190 metres of filament, the processing equipment he envisaged had to be exceptional. He also investigated the possibility of establishing a silk worm colony and even purchased 2,000 mulberry trees to be planted on recently acquired land in Devon. He learned to speak Italian for visits to Sicily in order to gain the necessary knowledge, sent one of his employees to Bengal for the same purpose and persuaded a French lady to come to Tiverton to instruct a group of mill girls in the art of silk weaving. He later decided not to proceed with this particular venture.

Heathcoat understood the needs of his farming neighbours and believed there was a demand for a steam-driven plough to dig deep into the ground and bring humus plus chalk deposits to the surface. In 1832 he and the drainage expert Josiah Parkes designed a machine which was supported on each side by 2.3 metres wide endless bands over a pair of very large revolving drums 7.9 metres apart. It incorporated a steam engine and the whole unit weighed 30 tonnes. A team of nine men and a boy were needed to operate it and initial trials at Red Moss in Lancashire went well. Further trials took place at Lochar Moss, near Dumfries, Scotland but arriving for the second day of the Highland Show the spectators were surprised to see the unit had vanished overnight. It was so heavy it could not be supported by the soft Scottish peat land and had sunk without trace never to be recovered! Despite this setback the agricultural side of the Tiverton business had been established in order to provide a shield in the event that the demands for textiles reduced.

A few years later, he developed a very ambitious specification to improve the building, lighting, heating and ventilation of mills. The plan was for a tier of machines on one floor to support the tier of machines on the second floor and so on, thus eliminating the need for arches, pillars, beams and joists. The building itself was thus simply a light shell. This was a totally new concept of industrial design widely copied and setting the pattern for factory construction in America and elsewhere.

The international political and commercial climate of the 1820's prompted Heathcoat to set up a factory in Paris to establish a safeguard against any slump in England. This factory was moved later to St Quentin, north east of Paris because of its good communications, skilled workforce and an existing excellent school for weavers.

The effect of this generally successful diversification strategy was to make the business more profitable and allow Heathcoat to continue philanthropic activities for his workers. He had always believed that work people were partners having a deep common interest in an enterprise. This philosophy was completely different to that of many other employers. He paid higher wages than the Midlands mill owners, employed women which gave them a level of financial independence, built houses for the workers and instigated the rule that children were not to be employed until they were able to read and write. At the time there was no compulsory universal education for children so he built his own school in Tiverton which was ready for pupils in January 1843 and took an active interest in the pupils' progress. It was the first factory school in the West Country and the building still stands today.

In 1831 his wife Ann died. The following year Heathcoat was elected as one of the two members of parliament for Tiverton but he still liked to direct his mind to solving mechanical problems and managed to develop a string of inventions including many to incorporate ornamental patterns in the finished product.

He died at Bolham House, Tiverton, in January 1862. During his life he had been a diligent craftsman, an inventive genius and an outstanding businessman with foresight and a flexible mind. He was a self-taught linguist, voracious reader and a person who compelled deep affection. He had sincerity and a modest but unshakable faith in his ability to succeed.

J A Knivett

OLIVER HEAVISIDE 1850–1925

Physicist and Electrical Engineer

In 1901, radio signals had been sent across the Atlantic for the first time, but the explanation of how they followed the curvature of the earth was a puzzle. Oliver Heaviside is known best to the public because he solved this puzzle but his life's work extended far beyond this single event.

His prediction was of a conducting layer of ionized particles being present in the upper atmosphere, which would act as a guide in bending radio signals round the earth. He made this suggestion in an article on telegraphy for the Encyclopedia Britannica in 1902, long before the actual existence of such a layer, about 60 miles (97 kilometres) up, was demonstrated experimentally nearly twenty years later. The 'Heaviside Layer' became familiar to radio listeners around the world. Today it is known as the 'Kennelly-Heaviside' or 'E' Layer, in recognition that a similar suggestion was made about the same time by Arthur Kennelly of Harvard University, USA.

Who was this man, Heaviside? He was born in mid-Victorian times into a family at a low social and economic level and who, with no formal education after the age of sixteen, eventually came to be accepted as the intellectual equal of the finest scientific minds of the day. He was a man who lived among his relatives, having resigned from his one and only job at the age of twenty four. He then devoted the next thirty five years of his life to first-rate scholarly research and the publication of technical papers of astonishing achievement.

Born in May 1850 in Camden Town, London, Oliver was the youngest of four sons of Thomas Heaviside, a wood-engraver from Stockton-on-Tees, and his wife, Rachel Elizabeth, the daughter of John Hook West of Taunton. In 1847, his mother's sister, Emma, had married Charles Wheatstone, one of the inventors of the telegraph, and through him both Oliver and his brother, Arthur West Heaviside, would be drawn into work on telegraphy.

His early years had been difficult. His father, he later said, was a 'naturally passionate man, soured by disappointment, always whacking us, so it seemed'. His mother, formerly a governess, was 'similarly soured by the worry of keeping a school'. An early bout of scarlet fever left him nearly deaf and, though his hearing later improved, he developed a lifelong tendency to isolation and self-sufficiency. After starting at his mother's 'dame-school', he went to school in the High Street, St Pancras, and then to Camden House grammar school, where he came first in Natural Sciences in 1865. Further schooling was financially out of reach. On the advice of his uncle, Charles Wheatstone, he continued his studies at home, concentrating on Danish, German and Natural Sciences, and doing some experimental work on electromagnetism. He also taught himself Morse Code.

In 1867, he was sent north to Newcastle to join his brother, Arthur West Heaviside, in the telegraph business, and a year later he gained employment as an operator with the Dansk-Norsk-Engelske Telegraph Selskab in Denmark with a yearly salary of £150. The Danish cable company was absorbed by the Great Northern Telegraph Company in 1870 and Oliver was transferred to Newcastle-on-Tyne, becoming Chief Telegraph Operator in 1871 at a salary of £175 per year.

Through unguided self-study he had been mastering existing mathematical books on calculus, differential equations and solid geometry. In 1872, he produced his first technical paper, 'Comparing electromotive forces' in the English Mechanic. This paper used mathematics no more advanced than algebra, but his second paper in the February 1873 issue of Philosophical Magazine made use of differential calculus and developed an exhaustive mathematical analysis of the sensitivity of the Wheatstone Bridge, used for measuring electrical resistance, and attracted the attention of leading electrical physicists of the day, William Thomson (later Lord Kelvin) and James Clerk Maxwell.

The publication in 1873 of Maxwell's 'A Treatise on Electricity and Magnetism' gave him direction and inspiration. He left his job at Newcastle in May 1874, possibly influenced by increasing deafness, and devoted the next few years to a thorough understanding of Maxwell's Treatise.

Heaviside's main discoveries centred on Maxwell's field theory and telegraphic propagation. The theory of signal transmission up to that time was incomplete. In a series of highly mathematical papers published between 1874 and 1881, Heaviside revised and extended it, showing in particular that the action of self-induction in coiled (highly inductive) submarine cables, taken together with the effects of resistance and capacitance, could cause a pulse of current not simply to diffuse along a wire but to surge back and forth in a series of waves or oscillations. The papers demonstrated the author's practical knowledge of real telegraph systems and resolved earlier, puzzling observations of their behaviour. They would be the key to the solution of the phase-distortion problem bedeviling and impeding the widespread use of the telephone.

Maxwell's field theory, expressed in his 'Treatise', focused not on electric charges and currents but on stresses and strains in the electromagnetic field around them. Heaviside's greatest advance came in 1884, when he found that, on Maxwell's theory, energy flows through the field along paths perpendicular to the lines of both electric and magnetic force, with the consequence that energy does not flow along within an electric wire, but enters it sideways from the surrounding field. He made it the key to revolutionizing the way Maxwell's theory was understood and expressed. When Maxwell died in 1879, he had left his theory as a long list of fundamental electromagnetic relations – 20 equations in 20 variables. Heaviside was now able to recast these into a compact and symmetrical set of four vector equations, now universally known as 'Maxwell's equations'.

Heaviside's career reached a watershed in 1887, when he helped his brother Arthur, by then a prominent engineer in the Post Office telegraph system, to write a paper on the new 'bridge system' of telephony. Applying his propagation theory to a circuit along which telephones were arranged in parallel, he found that the extra self-induction introduced actually reduced the distortion signals suffered in passing along the line. By loading the circuit with enough inductance and adjusting other parameters, distortion could be eliminated altogether. The paper was not well received by the then head of the Post Office telegraph engineers, who as Arthur's superior was able to block publication of the paper. However in an 1893 article in The Electrician, a weekly trade journal, Heaviside suggested that his idea of improving telephone transmission by loading lines with inductance might best be carried out by inserting coils at suitable intervals along the line. Such lumped loading eventually proved of enormous commercial value, but Heaviside never patented the idea and the profits were reaped in the USA, where a patent was secured in 1900.

In the meantime Heaviside had been active in the development of modern vector analysis and operational calculus for solving differential equations and in 1891 was elected a Fellow of the Royal Society. The testimonial to his contributions stated 'Learned in the science of Electromagnetism, having applied higher mathematics with singular power and success to the development of Maxwell's theory, of electromagnetic wave propagation, and having extended our knowledge of facts and principles in several directions and into great detail'. His collected 'Electrical Papers' were published in two volumes in 1892 and the first of the three volumes of his 'Electromagnetic Theory' (1893–1912) appeared in the following year.

Nearly 30 years before, Heaviside's older brother Charles had begun training in the music business as an instrument maker. Later, after marrying Sarah Way, he accepted a job in the music store of J. Reynolds in Torquay. Charles prospered and by 1889 he was a partner in the business, which was doing well enough to open a second store in nearby Paignton. Since leaving his telegraph job in 1874, Oliver had been living with his parents, initially in Camden Town and later in St Pancras. By the autumn of 1889 both his parents, Rachel and Thomas, were in their seventies and in less than good health. They, together with Oliver accepted the invitation by Charles to live above the Reynolds music store in Paignton at 15 Palace Avenue.

Through his working in solitude over many years, Heaviside had become a difficult and eccentric man, who cared nothing for the opinions of other scientists, with whom he had long and famous disagreements, but was convinced of the correctness of his own endeavours. Surrounded in Paignton not only by his parents, but now also by his brother's large family of five children, his social horizons were somewhat broadened and this was to become a happy period in his life. One of the family later wrote about those years: 'I remember, in the big upper stock-room of my father's music saloons, how with my father playing a march, Oliver, at the head of us, would march around, in and out among the pianos (perhaps a dozen or more), we hanging on to his coat tails in a row, one behind the other'. Oliver, himself, played both the Aeolian harp and the ocarina, a small egg-shaped porcelain wind instrument.

His parents died in 1894 and 1896. That same year 1896 a civil-list pension of £120 per year was secured for him and he was persuaded to accept it. Although he had long lived in near poverty, he had been too proud to accept repeated offers of charity from the Royal Society and others.

In 1897 he left Paignton and rented a house in nearby Newton Abbot – Bradley View, 2 Totnes Road. 'Behold a Transformation!' he wrote. 'The man 'Ollie' of Paignton, who lives in the garrets at the music shop, is transformed into Mr Heaviside, the gentleman who has taken Bradley View'.

It was while he was here that he made his famous prediction on the Heaviside Layer and in 1905 was given an honorary doctor's degree by the University of Gottingen, Germany. He invested in a safety bicycle, with a spoon brake that pressed on the front tyre, and spent many happy hours cycling around the Devon lanes. His relations remember him whizzing down the narrow lanes, whistling with his feet on the front forks because the pedals were turning too quickly as the bicycle had no freewheel. One of his favourite destinations was Berry Pomeroy Castle. He also cycled to Little Haldon and to his relatives in Babbacombe and Torquay.

However local people did not understand him. Youngsters threw stones at windows in the house and wrote unpleasant remarks on the front gate. As they played in nearby fields (now Bakers Park) they often trespassed in the garden to steal from fruit trees. He had long suffered from indigestion and what he called 'hot and cold' disease, and being left to cook and keep house for himself, his health declined further. He developed gout and was constantly plagued with bouts of jaundice.

After suffering an especially serious illness in 1908, his brother Charles arranged for him to board with Mary Way, Charles' sister-in-law, at her Torquay home, Homefield, in Lower Warberry Road, high on a hill overlooking Torbay. She would have the downstairs of her home, while he would have the upstairs. And that is where he stayed for the remaining seventeen years of his life.

Mary Way was a kind, good-natured woman in her middle-sixties when Oliver came to her, and she displayed extraordinary patience and tolerance for her sharp-tongued, crotchety house-mate. She also provided the human touch, as well as food cooked by someone who knew what she was doing. His situation brightened to the point that sometime in 1910 he wrote that he expected to live another tenty five years. Sadly he published little after 1905 and almost nothing after the third volume of Electromagnetic Theory finally appeared in 1912.

Living with such a man on a daily basis, with his constant demands to come before anything else put a terrible strain on Mary Way. In 1914 his civil-list pension was increased to £220 per year and Miss Way eventually sold the house to him in 1916 and moved out. A local policeman, Henry Brock, helped tend to his affairs, Brock's daughters also visited and helped and various scientific friends paid occasional visits, but he grew increasingly isolated and eccentric.

In 1922 he agreed to accept the Institution of Electrical Engineers' newly instituted Faraday medal. When the president of the Institution went to Torquay to present the award, he found Heaviside to be ‘fully competent’ and still wittily acerbic.

On 4 January 1925 he was found unconscious by Constable Brock and was moved to Mount Stuart Nursing Home in Torquay, where he died on 3 February 1925. He is buried with his parents in Paignton cemetery.

He is commemorated on plaques erected by the Torbay Civic Society on the premises where he lived in Palace Avenue, Paignton, now Barclay’s Bank, by the Institution of Electrical Engineers at Homefield and also at Torquay Town Hall. A similar plaque has been placed in Totnes Road, Newton Abbot, by the local Civic Society. He is also remembered in the street name ‘Heaviside Close’, which along with Brunel Avenue and Froude Avenue are in the Watcombe area of Torquay below Brunel Manor. As a lasting honour, craters on Mars and the Earth’s moon have been named after him.

R J Dee