The Spirit of Engineering

The Lives and Achievements of
Inventors and Designers
in the West Country

Compiled by Members of the
Retired Chartered Engineers' Club – Exeter
to commemorate the Club's
Twentieth Anniversary
June 2006

In memory of the late
Bob Flux
Founder of the
Retired Chartered Engineers' Club
Exeter

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INTRODUCTION

By John Conolly B Sc F R I N A

Chairman of the Retired Chartered Engineers' Club – Exeter

This book has been compiled by members of the Retired Chartered Engineers' Club, Exeter to commemorate its twentieth anniversary.

The Club was founded by Robert W Flux F I E E in June 1986. Membership quickly reached one hundred and has remained at that level for twenty years.

In addition to providing members the opportunity for social fellowship and to remain aware of new technical developments, an important Club objective is the encouragement of young people to enter the engineering professions.

Members hope that those about to embark on their chosen careers will find inspiration from the lives of individuals whose accomplishments have had an enduring effect on today's world. There are countless examples of 'the spirit of engineering' and this book records the achievements of just some of the characters who lived in and around the county of Devon.

Another of the Club's activities is an ongoing project to install commemorative plaques at places associated with those who have made significant contributions to the field of engineering. Currently plaques are installed to honour George Parker Bidder, James Green, James Meadows Rendel, Percy Carlyle Gilchrist and Sir Frank Whittle at Mortenhampstead, Exeter, Whiddon Down, Lyme Regis and Chagford respectively. With these tributes it is hoped to encourage even more interest in the engineering heritage of the West Country.

FOREWORD

By Andrew Ives F I Mech E F I E E

President of The Institution of Mechanical Engineers

The individuals whose lives are described in the following chapters have one characteristic in common – they achieved their ambitions!

Each one was driven by inspiration and dedication to reach a goal and it matters little that they were known as inventors, mathematicians or ironmongers – they all possessed the 'spirit of engineering' that leads to success. The triumphs, frequently accomplished against all the odds, produced outstanding improvements in the quality of life for their own and following generations.

The 19th and 20th centuries saw amazing developments in every field of technology and society continues to benefit from the application of technical expertise. Innovative communication systems, sophisticated medical equipment, new methods of power generation, and the latest products from some of the new sciences such as nano-technology are all around us.

At present, the central issues facing our world are concerned with the effects of pollution and the depletion of irreplaceable resources. Through research, scientists, physicists, chemists, geologists and many others will continue their vital contributions to resolve these problems, but engineering is the activity that makes the world habitable. It converts the results of this research in to solid, practical, useable products and processes.

This book has been compiled by Chartered Engineers who have spent a lifetime involved in worldwide projects. The achievements of our predecessors have been captured in the fervent hope that these will generate the enthusiasm of the 'spirit of engineering' in today's youth – the engineering pioneers of the future.

JOHN TAYLOR 1779–1863

Civil Engineer and Mining Entrepreneur

The quiet town of Tavistock stands on the edge of Dartmoor and it is difficult to believe that at one time its character could have been likened to that of the Klondyke Gold Rush in the Yukon, Canada. In 1796 the mineral ores, particularly copper, discovered in Devon attracted much attention and the population of the town doubled almost overnight. Surrounded by industrial mining activities Tavistock also was home to wool mills, foundries and tanneries pumping smoke, dust and dirt onto the houses and streets. Into this arena stepped a nineteen year old young man, John Taylor, who was to become acclaimed as the 'Patriarch of British mining'.

John was born in 1779 in Norwich, about as far away from any form of mining activity as it is possible to get in England, the first of seven children in a relatively prosperous family. His father was the owner of a yarn manufacturing business and instilled in his children a strict moral code including meticulous control of financial matters, unflinching honesty, propriety and trustworthiness in all their dealings. These qualities were to underpin John's subsequent successful career.

Early education was provided for the children by their mother Susannah and eventually all the sons became prominent members of many influential learned societies. She taught them the 'three R's' plus foreign languages and gave John mathematical instruments and a turning lathe to encourage his mechanical pursuits. He later attended a day school which provided a grounding in chemistry plus other scientific subjects and subsequently he became apprenticed as a land surveyor and civil engineer.

At the end of his apprenticeship Taylor's career suddenly changed course in a quite unexpected manner. He had been invited by friends, the Martineau family, to join them on a visit to one of the Devon copper mines east of Mary Tavy village in which they had a financial interest. His observations and comments about the mining operations so impressed them that they initiated an invitation for him to take on the management of this 12 hectare mine called Wheal Friendship. He accepted.

This was a most unusual situation since managers were invariably appointed from the ranks of those experienced in mining matters. The nineteen year old civil engineer from Norwich was faced with many challenges both managerial and technical and he must have seemed very young and inexperienced. Once in office however, he proved to be an immediate success, quickly identifying two of the major problems at the mine. One was associated with the efficient 'dressing' of the ore and the other was with its transportation to the nearest navigable port, Morwellham Quay on the River Tamar.

His ideas transformed the dressing floors into the most mechanised in the South West and the mine into one of the most profitable. 'Dressing' is the term applied to the various sorting, crushing, cleaning and grading processes to which the mined ore is subjected. His operating principle was to make good payment schemes for the workforce and initiate major capital investment for long-term profitability via mechanisation using latest technology. This approach was popular with the miners but was not always the philosophy of managers in rival mines who were often interested only in short term gains.

The problem of transporting ore efficiently to Morwellham Quay was twofold. The terrain and poor roads meant that teams of packhorses had to be used which was both time consuming and expensive. Taylor proposed a canal between the Rivers Tavy and Tamar. His planned route was not the most direct, but allowed mineral excavation at the same time as canal digging. Although the work started well, later tunnelling through hard slate deposits proved more difficult because of ventilation and flooding problems. He designed and installed special ventilating equipment and for this was awarded a medal by the prestigious Society of Arts. The canal project took thirteen years to complete and a part of it can be seen in the centre of Tavistock today. The basin at the other end of the canal was 73 metres higher than the River Tamar and an incline with double grooved rails was constructed. Barges were loaded onto trolleys connected to chain and windlass for transfer to the low level. Mineral ores and large quantities of arsenic went down to the quay and coal plus lime were returned up on these barges. A very large water wheel was installed to provide power for the many activities which included barrel-making for the arsenic. Soon Morewellham Quay became the hub of communications for the Tamar Valley industries with a world wide importance exceeding that of Liverpool. The canal fell into disuse only when the railway between Plymouth and Tavistock was constructed.

Under Taylor's direction the Wheal Friendship Mine continued to be developed with deep workings to 400 metres. The main source of power for the mines was water via leats and seventeen water wheels were installed, one an impressive 15.5 metres diameter. Within a year of office Taylor had developed enough confidence to take a direct financial interest in the re-opening of a neighbouring copper mine Wheal Crowndale (wheal is the Cornish word for mine – frequently used also in Devon). This too was a successful venture and enhanced his reputation.

By this time he had married Ann Pring of Awliscombe, near Honiton, and they lived at Whitchurch eventually producing a family of three daughters and the two sons John and Richard who were later to play key roles in the management of the business.

Unexpectedly, at the age of thirty two, Taylor left Tavistock receiving a heartfelt goodbye from many miners and their families whose respect and regard he had earned by managing so effectively the mines' affairs and the workers well-being. The move perhaps was prompted by the challenge of scientific and technical problems in the new but rapidly developing chemical industry.

He joined his brother Philip who was setting up a chemical manufacturing facility in Essex first concentrating on metallurgical problems associated with manufacturing sulphuric acid, then on a scheme to produce gas from oil instead of coal. The brothers applied for, and received, the patent for a process to refine and purify sugar. The following year the business was expanded again, this time into mechanical engineering manufacturing portable printing machines. John Taylor however was still very much interested and involved in mining affairs and as these were making more and more demands on his time he withdrew from all formal involvement in the chemical business.

His return to the mining industry was made via lead mines in Flintshire where he introduced the equipment and practices developed with such success in the South West. These mines soon became the most profitable in their region.

Taylor gradually became re-involved in projects at Tavistock with a reputation that allowed greater areas of control including the responsibility for the overhaul of port facilities at Morwellham Quay. He acquired land in Tavistock and built offices plus other premises for the mining business.

Soon his ambitions and skills resulted in involvement in mining activities in all regions of the British Isles including Ireland and Scotland. One enterprise alone in Gwennap, employed three thousand workers, dominated the district and endowed Taylor with an international reputation. He was associated with the Great Consols Copper Mine at New Bridge near Tavistock which ultimately produced over 600,000 tonnes of copper and was so successful that within six months after its opening each £1 Share was worth £800. Devon and Cornwall were soon satisfying more than half the world's needs for copper. By 1824 when he was forty five years old he controlled nearly forty large mining companies and several consultancies so it was not surprising that he set his sights on overseas opportunities.

The agent for the owners of the fabulously rich silver mine Real del Monte in Mexico contacted Taylor and after some negotiations a company was formed to operate the works. He hoped to introduce the methods for efficient mining operations which had been so successful in the UK but problems in Mexico proved to be of a much greater magnitude. Administration and communications were very difficult due to the distances involved. Time intervals could be measured in months for the answer to an operational enquiry being received back in Mexico from England, by which time site circumstances had usually changed. Delays occurred for the delivery of equipment spares and supplies from England since there were no local dealers and expensive haulage along two hundred miles of poor roads exacerbated the situation. Machines had to be shipped in parts for re-assembly on site. Good local workers were scarce and not amenable to the new forms of contract. Personnel transferred from England to supervise the workforce expected very high salaries. Sickness on a large scale was experienced and bandits frequently made raids for the payroll. In addition, there were severe technical difficulties in excavation and ore dressing plus a grave underestimate of the mine's flooding problems. The mine failed to produce a consistent dividend for the stockholders and in 1848 they voted to close the Company. This was of course a great blow to Taylor but was the only real major disaster in his long career which, in addition to projects in Britain, included overseas operations in America, Spain, France, Germany, Italy and Australia.

Notwithstanding extensive business commitments Taylor was involved in many other activities. He helped to establish an elementary school in Tavistock along with the library there, was elected to the Geological Society of London, contributed to the founding of the British Association for the Advancement of Science and assisted in the affairs of the University College of London. His sincere interest in the well-being of miners prompted him to crusade for a School of Mines so they could be educated in the latest technology for their industry. From these efforts evolved the Camborne School of Mines. His home saw many social gatherings with friends such as George Stephenson, Charles Babbage, Felix Mendelssohn, and members of the Brunel family.

In the 1850's he was in his seventies, suffered several health problems and gradually retired from business and technical activities. He died 1863 after a long and incapacitating illness but the business he established continued to expand and prosper for more than another century.

In sixty years of active working life, John Taylor had assembled a business empire matching in scale and geographic extent the largest in any branch of industry or commerce. His role in the creation of this empire was not so much as an inventor of brand new technology but more as a gifted intermediary. He identified the cause of a problem, suggested a solution and then motivated the inventor and user. A brilliant informed administrator and a clear thinking innovator joining technology with practicality, John Taylor fully justifies the title 'Patriarch of British Mining'.

J A Knivett

THOMAS FOWLER 1777–1843

Inventor

Thomas Fowler was born in Great Torrington, Devon in 1777 and after receiving a basic education in a small school in the town was apprenticed, at the age of about thirteen, to a local fellmonger, a seller of animal skins. However he had a yearning for mathematical study and the vision of a very different future.

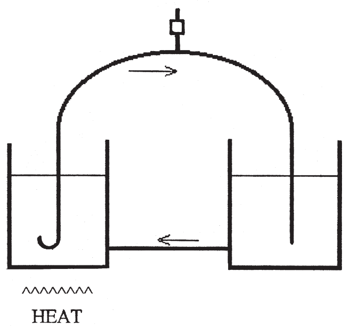
After long days treating animal skins he would spend much time at night studying mathematics and by the age of sixteen had thoroughly mastered the difficult subject of differential calculus. Few could have been more completely self-taught.

Mathematicians in those days were scarce in North Devon as well as in the great centres of education throughout the country but his dedication to study was eventually rewarded. By 1830 he had become established in the town as a bookseller and printer using the printing machine he constructed to drawings of his own invention. Later he became clerk then manager and partner of the only bank in Great Torrington, organist of the Parish Church and, by standing as a town councillor, a valued member of the local community.

At the age of thirty five, Fowler married Mary Copp, a twenty one year old local girl, who became his life long partner. Both Thomas and Mary came from large families, each having three brothers and three sisters. Over the period of twenty three years, Mary became the mother of their eleven children, a number of whom made their mark in life. One daughter, Caroline, was sufficiently literate to become an expert compositor, setting type for printing, working for her father in his printing business. Their son, Hugh, went on to publish several religious and educational books and in the later stage of his academic career became Headmaster of the Cathedral School in Gloucester. Another son, Charles, was appointed Professor at the Royal Academy of Music and became a noted concert pianist and composer.

In 1828, Fowler invented and patented the first convective heating system which was the precursor to the modern day central heating system. It was called a 'Thermosiphon' and the principle by which it works is very simple. It is based upon the idea that water may be heated and made to circulate through a siphon, as well as through horizontal pipes or, with force, through pipes in any direction provided that the height of the siphon is not greater than to be counter-balanced by the pressure of the surrounding atmosphere. Whenever heated fluid circulating through pipes is used for the delivery of heat, this principle is applied. It is the basic method used in today's central heating systems installed

FOWLER'S THERMOSIPHON



Curved pipe connecting the tanks is primed with water via top valve. Left tank is heated and the lighter warm water rises in the pipe then descends into the right tank starting a siphoning action. Cooler water transfers from right to left via lower straight pipe and circulation continues. Lower left hand bend prevents any rising air bubbles from entering the curved pipe, lodging at apex and breaking the siphoning action.

throughout the world to provide a comfortable temperature for modern living conditions.

Although this system was patented by Fowler the laws of the time were weak and flawed. By introducing any small modification or change to the original design features the resulting new version would not be covered by patent. This meant that others could reproduce Fowler's invention without penalty of any kind which, of course, soon happened. This loophole caused Fowler great distress as he was left helpless to prevent his invention being copied everywhere by others. The only remedy would have been to recourse to costly legal proceedings but, even if he had the means to do so, a successful outcome could not be assured.

During the 1830's Fowler was offered, and was pleased to accept, the appointment of Treasurer to the newly established Torrington Poor Law Union thus embarking upon a path that would lead to his next and most significant invention.

As treasurer of the Poor Law Union he was responsible for assessing and calculating the payments for each of the Parishes. Finding the necessary calculations cumbersome and tedious he determined to find a way of simplifying this procedure. Common logarithms were available at this time to help with the process but Fowler was not satisfied with these complex calculations and began to search for a simpler method. This led him to attempt to automate the calculations by using reference tables.

His solution was typically brilliant and led, in 1838, to the printing of Fowler's 'Tables for Facilitating Arithmetical Calculations'. These tables used a method based on his realisation that any number might be produced by a combination of the powers of 2 or 3. The first part of the Tables is in binary, a table of indices of the power of the number 2 from 1 to 130048. The second part is in ternary, or a table of indices of the power of the number 3 from 1 to 3985607. In binary, each figure increases twofold and in ternary, each figure increases threefold.

The thinking behind these tables was entirely new, and although the properties of the powers of the numbers 2 and 3 were known to mathematicians at the time, the want of some particular application for their use had not been established and had not therefore found an arithmetic use.

The binary system can best be described by imagining a horizontal bank of pigeon holes each capable of displaying just two characters, 0 and 1. The right hand window indicates the number of 'units' under consideration. The one to its left indicates the number of 'twos' under consideration, the next the number of 'fours', then 'eights' and so on. To indicate the quantity thirteen, the pigeon holes' display is; [1] [1] [0] [1].

Similarly, the ternary system uses three characters 0, 1 and 2 and windows' values progress from right to left in factors of three. ie. 'units', 'threes', 'nines', twentysevens' and so on. To indicate the quantity forty six, the display is; [1] [2] [0] [1].

Such was the success of these tables in reducing the time taken by accountants to produce their figures that Fowler was determined to continue his work in this field. Thus, between 1838 and 1840, he worked behind closed doors developing his thoughts on ternary arithmetic and extending his knowledge further with the creation of a mechanical calculating machine.

The first machine was constructed almost entirely of wood and made by Fowler himself on his premises at Great Torrington. Such was Fowler's anger and bitterness at the way his invention of the Thermosiphion was pirated and copied that he went to great lengths to protect the details of his machine from prying eyes. The 'uniqueness' of Fowler's ideas to mechanise calculation was based upon his realisation that he could simplify the whole process of calculating by using just the indices of the ternary scale rather than the values that the indices represent. His choice of sliding rods rather than rotating wheels in his machine was also significant in reducing mechanical complication, particularly in 'carry-over' operations. However, his excitement at completing this achievement was tempered by the dilemma he now faced of how to bring his unique invention to the attention of the wider scientific community without releasing any drawings or details that would enable others to replicate the machine for their own benefit and profit.

Fowler found a solution to this dilemma in the person of the

Rev. John Moore Stevens, Archdeacon of Exeter and someone in whom Fowler could trust, having a number of personal connections with great Torrington. Stevens was able to arrange a demonstration of Fowler's machine for Charles Babbage and others he felt might be interested. This contact with Babbage who was also at the forefront of the development of mechanical calculating machines at the time was to prove significant. There had been previous attempts to mechanise calculations in previous years but these devices had proved to be most unreliable and of limited application. Thus scientist, astronomers, navigators, engineers, surveyors, bankers and others all continued to rely on printed mathematical tables.

Fowler's machine which was 1.8 metres long by 0.3 metre deep by 0.9 metre wide, was exhibited and demonstrated before members of the Royal Society in May 1840. Later, the then Astronomer Royal, Professor George Airy, was to promote the machine to a gathering of the British Society for the Advancement of Science in August, 1840.

Charles Babbage, George Airy and many other leading mathematicians of the time witnessed Fowler's machine in operation. These names have become famous in the history of science, yet today it is difficult to locate many references to Thomas Fowler even though his machine was said to be superior in many respects to Babbage's calculating machine. Fowler's designs anticipated the modern computer by using a ternary calculating method. This is in contrast to Babbage's machine which performed a decimal calculation, an approach which made his machine very complex.

Fowler went on to demonstrate his machine at Devonport in 1842, and to construct a greatly improved version the following year. Tragically he then fell ill and died on 31 March 1843, without fulfilling the hopes of seeing his calculating machine receive the acceptance he believed due to it, as indeed did many others. If he had released some diagrams, drawings and details of its construction perhaps it would have been a different story, but his unhappy experiences with the Thermosiphon had such an impact on him that he felt he could not run the risk of a similar thing happening again.

Perhaps he was right to trust no-one in this developing market of knowledge; history is littered with examples of disputes over patent rights and litigation, but as a result of his actions Fowler ultimately was denied the scientific investigations of the whole principle of calculations and the acceptance of a machine that he so much desired.

It is hoped that one day the full significance of his invention will be realised and that he will receive the recognition he deserves. He was a man of remarkable intellect, perception and imagination who had a rare ability to move beyond accepted reasoning and produce simple, clear solutions to the most complex problems. The genius of Thomas Fowler, a true son of Devon, must never be forgotten.

N S Macaulay

JAMES GREEN 1781–1849

Civil Engineer

James Green was born in 1781 in Birmingham. His father was a civil engineer and contractor in Warwickshire and the adjoining counties and it was from him that James received his early experiences in the field of engineering.

Between 1800 and 1807 he was employed by John Rennie, one of the greatest civil engineers of the time, as an assistant working on extensive surveys, canal works, and drainage of bogs and fens and the design of engineering works generally, both in England and Ireland. At this time, the repair and replacement of Dymchurch, Sussex, seawall came particularly under Green's care and the reconstruction of the sea lock of the Chelmer and Blackwater Navigation was entirely entrusted to him by the landowner the Earl of St Vincent.

It was from here that Green came to Devon, and in July 1806 he became responsible to Rennie for the instruction of a local surveyor, Charles Tozer, at Totnes. Rennie was at that time reporting to the Duke of Somerset on ways of improving the navigation of the River Dart below Totnes bridge. Rennie also employed Green on a survey of the rock at Cattewater intended for use for the construction of the breakwater at Plymouth, which scheme commenced in 1812.

Meanwhile in a report to Lord Boringdon of Saltram in December 1805, Rennie had proposed an embankment from Pomphlett Point to Saltram Quay. This had a favourable reception and Lord Boringdon contracted with Green for the construction of the embankment 890 metres long to enclose 70 hectares. Two years later, following the collapse of the newly rebuilt Fennny bridges near Honiton, Green contracted for the design and construction of a replacement bridge across the River Otter; it had three spans of 12.8, 14.6 and 12.8 metres in brick-work and was 6.1 metres wide between the parapets. In 1808 the Plymouth Eastern Turnpike Trustees allocated funds for the construction of a bridge over the River Yealm, at Lee Mill, to be designed and supervised by Green.

Also in 1808 a committee of magistrates had been reminded of a letter of July 1800 from the Clerk of the Peace of Shropshire giving information on the conditions of appointment of Thomas Telford as their county Surveyor. The Devon magistrates decided to dispense with their six surveyors and appoint one civil engineer as their county bridge surveyor. Green was appointed at a salary of £300 per annum and therefore became Devon's first county bridge surveyor, a title which was quickly to become county surveyor when he took responsibility for the county buildings. As surveyor, he was contracted to inspect over two hundred and thirty bridges every year, to report deficiencies to Quarter Sessions and to obtain the magistrates' sanction to carry out repairs for a particular sum of money. Such was the on-going development in Devon that now, in the 21st century, there are 3,500 bridge structures in the county. Green was allowed to seek outside work and so put a series of advertisements in the Exeter Flying Post informing the noblemen and gentlemen of Devon and the adjoining counties that he had taken up residence in Exeter and was soliciting their patronage.

By 1820 some thirty-six bridges had been built or widened to take the rapidly expanded traffic of the day. Three span bridges were Fenny, New at Tawstock, Cadhay over the Otter, New at Kingsteignton, Emmets over the River Dart, Hele at Hatherleigh, Head over the Mole, Cowley near Exeter, Steps at Dunsford, Weston near Honiton and Brightly north of Okehampton. Standard widths were agreed with the justices for the most important turnpike roads 5.5 – 6.1 metres, for the lesser turnpike roads 4.6 – 5.5 metres, and for other roads 3.7 metres clear.

Green commenced work on a canal from Exeter to Crediton, but this project was halted almost immediately. For Lord Rolle and others he carried out land reclamation of Braunton marshes on the estuary of the River Taw where, with John Pascoe as his surveyor, an embankment 3,660 metres long enclosed 526 hectares and was completed in 1814. At Budleigh Salterton in the estuary of the River Otter, Lord Rolle commissioned Green to reclaim an area 1,830 metres long by 300 metres wide, enclosing over 567 hectares. In October 1813 he joined Joseph Whidbey, John Rennie and others in advising the Admiralty Solicitor that enclosing a creek at Alverstock, near Gosport, would interfere with the tidal flow near Portsmouth!

A most important architectural assignment had come to Green in 1810 when he transformed Buckland House, damaged by fire in 1798. His work there led the architectural historian Sir Nikolous Pevsner to say that his work showed him to be an accomplished innovative practitioner in the neo-classical style which was at this time becoming popular in Devon. His construction of St David's Church, only 100 yards from his home Elmfield, was commenced in 1816 and although it was replaced in 1897, the appearance of the church was well-known in Exeter from its distinctive octagonal tower with eight Doric pillars surmounted by a rounded dome.

In 1819 Green reported to the trustees of three turnpike roads, the Plymouth Eastern, the Ashburton and the Exeter, concerning the road from Exeter to Plymouth. As always in those days the problems were the need to reduce unnecessary ascents and descents, increase the road widths and improve the surfaces. In all, some 22.5 kilometres of road were realigned.

Early ideas for a canal from Bude to Launceston had surfaced in the 1770s and Robert Fulton had already suggested that inclined planes would be more suitable than locks for the 110 metres rise from the sea to the River Tamar. Inclined planes generally incorporated rails with trucks onto which the craft were loaded for them to be raised, or lowered from one level to another. In 1817 the fourth Earl Stanhope commissioned Green to prepare a plan of a possible line for a canal and Thomas

Shearm was appointed surveyor. Work began in 1819 and Green built 56 kilometres of canal with six inclined planes fed from a dam across the upper reaches of the River Tamar; a reservoir was included. Green invested £3,000 of his own money in the canal but the shares produced no return in his lifetime.

During the decade from 1821, one important scheme followed another. Some forty-six bridges were built or widened, including the magnificent five-arched Beam aqueduct north of Torrington and three-span bridges at Clyst Honiton, Gosford over the Otter, Long at Cullompton, Otterton, Tinhay over the Wolf, and Newnham over the Taw.

In 1823–24 Green combined with Underwood, the Somerset County Surrveyor, to produce plans for a new House of Correction to stand alongside the County Gaol at Exeter and Green became responsible for the construction of the £12,700 building. At this time his salary was £550 p.a. but he insisted that the County also paid him the fee of £87 16s. The magistrates eventually agreed but this matter caused resentment that was to surface in 1831 and cause a reduction in salary.

Green became heavily involved in canal work. The Bude canal was completed in 1824, a fine example of the use of 6 ton narrow boats and inclined planes. In 1824 he commenced the Torrington canal for Lord Rolle, extending from downstream of Weare Gifford to a point alongside the river south of the town and it was here Rolle also employed him to build new grist mills and erect the machinery.

Meanwhile in 1820 the City of Exeter had asked him to advise them on improvements to their canal and work proceeded on rebuilding the entrance sluice, providing a uniform depth of 3 metres lowering the cill of the Double Locks and constructing a culvert under the canal to drain land fed by the Alphin brook that had been cut off by the canal near Double Locks when the canal was first built in 1566. In 1824 he proposed that the canal should be extended 3.2 kilometres from opposite Retreat House to Turf, where vessels drawing 3.7 metres could navigate the estuary at all tides. The canal was further deepened but at Exeter there was solid sandstone below the river quays. Green therefore proposed the construction of a basin, independent of the river. Telford was consulted, and work proceeded on this project, the canal being opened to Turf in 1827 and the new basin completed three years later. Green was voted the Freedom of the City of Exeter in October 1830, his recognition was significant and unusual in view of the fact that he followed the beliefs of the Quaker church.

The idea of linking the Bristol and English channels had been alive since 1768 and in 1821 Green was asked to make a survey. He proposed a tub-boat canal to run from the existing canal near Taunton to Beer, and in 1824 Telford was also engaged to make a survey for a ship canal with Green signing the plans. Although an Act was obtained no more was heard of this scheme.

During 1823–24, in conjunction with Joseph Whidbey of the Admiralty, Green surveyed and reported on harbours of St Ives and Ilfracombe, and in 1827 he surveyed the bay for a harbour at Combe Martin. Also in 1823 he proposed improvements for Bridport harbour but instead a scheme prepared by Francis Giles was carried out in 1824.

In 1829 a scheme prepared by Green for a dock at Cardiff was adopted by Lord Bute and submitted to Parliament, but on the advice of Willliam Cubitt it was altered and West Bute Dock was subsequently opened in 1839.

Now having firm links with the Exeter Turnpike Trust, Green was invited to make a survey of the road between Exeter and Crockernwell, the Trust's limit on the way to Okehampton. He produced a new route from Pocombe bridge to Tedburn St Mary using the valley of the Alphin brook and it was opened in 1824. For the Countess Wear Committee of the Trust he rebuilt the swing bridge over the canal the following year.

In conjunction with a proposal to build Laira bridge, the Plymouth Eastern Turnpike turned to Green to improve the roads from the eastern bank towards Totnes. He produced a plan for a direct road to Yealmpton, some improvements to Ermington and then a new road up the Ludbrook valley, by-passing Ugbrook to Ladydown; this required new bridges over the River Yeo, the Ermer and the Lud. In 1825 a three-mile diversion was made just north of Sandwell to run directly to Totnes and again he was asked to supervise the building of a new bridge over the River Harbourne. In 1827 he was responsible for a new road to Yarcombe for the Chard Turnpike Trust.

In 1824 Green had built Eggesford bridge over the River Taw. This route saved over 300 metres of unnecessary ascents and descents and provided Green with the opportunity to build four more bridges with a view to them being taken over by the county.

As a result of a complaint that too much was being expended on the maintenance of the prisons, it was proposed in 1830 that Green's salary should revert to £300 per annum and a letter from Rendel was produced offering to perform all Green's duties for £300. Green accepted the reduction in salary but was forced to look outside the county for as much consulting work as he could command. Besides building another twenty-seven bridges in the next decade he turned his attention once more to canals and other proposals. For the Barnstaple Bridge Trust in 1834 he widened the existing 16-span bridge by cantilevering delicate and attractive footways 1.2 metres wide on each side using ironwork from the Neath Abbey Iron Company. In 1832 he proposed water supply, sewerage and railway schemes for Torquay.

Rennie had built over 17 kilometres of canal from Tiverton to the Devon-Somerset border to convey limestone from the Canonsleigh quarries, and this had been opened in August 1814. The Grand Western Canal proprietors wished to extend their canal to Taunton to join the Bridgwater and Taunton Canal. The distance was only 21 kilometres but the difference in level was 80 metres Green had presented a report to the company in 1829, advocating boats of 6.1 metres by 1.8 metres carrying 5 tonnes, six of these to be drawn by one horse. In a further report in 1830 he suggested one inclined plane and seven perpendicular lifts, with boats of 8 tonnes, at an estimated cost of £61,324. Work commenced in June 1831, but operating difficulties were experienced with both the lifts and the inclined plane and within five years Green had ceased to be engineer. Work was completed in 1838 at a cost of £80,000.

In 1831 a canal for Chard was proposed and Green was consulted. He proposed the use of two lifts, two inclined planes and two tunnels, all at a cost of £57,000. Work got under way in June 1835 but soon Green ceased to be engineer, no doubt because of troubles with the Grand Western Canal; the Chard Canal was completed by May 1842.

The silting of the Gwendreath estuary in South Wales in the early nineteenth century had caused Kidwelly to lose its facilities as a port for the coal of the valley. The Kidwelly and Llanelly Canal and Tramway Company had obtained powers by an Act of 1812 to extend the canal up the valley to beyond Cwm Mawr about 76 metres above sea level and in 1832 the company called in Green to report on extending the canal beyond the point reached in 1824. In 1833 he recommended two locks and then three inclined planes at an estimated cost of £35,845. By 1834 work was well advanced but the following year Green informed the directors that he was unable to finish his inclined planes. He was dismissed in 1836, in the same year being dismissed as engineer to Burry Port as the result of the collapse of a dock wall.

In 1830–31 Green's home was recorded at 38 Southernhay Place while in 1833, 1834 and 1836 it was in Magdalen Street. Following the above problems a notice of bankruptcy appeared in the Exeter Flying Post in March 1837 following an entry in the London Gazette. By 1838 Green had moved out of Exeter to Alphington, no doubt to economise. The sums involved in his failed contracts were probably so large that he had no opportunity to recover them from his income during the closing twelve years of his life. This would have affected his status in the Religious Society of Friends, who might have disowned him because of his bankruptcy.

A contract for a dock in Newport, Gwent, had been let in 1835, but within two years the contractors were in trouble and some time around 1840 Green was appointed to take over from the previous resident engineer to complete the works. He took up residence there but in the same year the Devon justices were told that Green could not continue his work in Devon satisfactorily without deputising the minor matters to his son. Some magistrates complained that they were having to do the work of the surveyor and Green was given twelve months notice from the Midsummer 1840 Sessions.

So Green left the county's employment and in 1841 was listed as living in Heavitree with his son as 'Green James and Son, Civil Engineers and Land Surveyors, Portview Cottage, Heavitree'. Green brought the work at Newport Dock to a successful conclusion in 1843. He then settled in London but because of the active competition of younger men, he was not so extensively employed as he might have been.

In 1844, because of his knowledge of the estuary of the River Exe, Green was consulted on the building of the South Devon Railway. Exeter City opposed the Bill to safeguard its navigation rights in the estuary and Green made a report in the same year. The essence of his evidence was that the embankment alongside the estuary would enclose 41 hectares which would make a significant difference to the movement, and hence the scour, of the water in the estuary as it crossed the bar.

The floating harbour of Bristol was made feasible by constructing locks on the river downstream of the docks and diverting the River Avon along a new channel to the tideway below the locks. No thought was given to intercepting and carrying off the sewage of the city away from the harbour. Further sewage was brought in by the tributary River Froome, which passed through a populous part of the city. In 1846 Green was instructed by the Council to advise on the measures for abating the nuisance. He recommended straightening the River Froome, making it of uniform width to give greater scour of the bed and intercept the sewers that discharged into it. The Council considered that it could not proceed because it did not have the legal powers but further instructed Green to advise on action to be taken between Stone Bridge and Castle Moat. The report was made in March 1846 and during the summer works were carried out at a cost of £4,537 to clear this area of accumulated sludge. Green presented a paper on these reports and works carried out to the Institution of Civil Engineers in February 1848. He had been proposed as a corresponding member by Telford in 1824.

In May 1805, Green had married Elizabeth Dand at St Martin's, Birmingham. A son, Thomas, died aged three in 1815, but another son, Joseph, was born in 1817. James Green died from a heart attack on 13 February 1849 at 67, Manchester Buildings, Westminster, and was buried on 28 February at Bunhill Fields as a non-member of the Religious Society of Friends, though his connection was enough for a Quaker burial. His death was noted in the Bristol Mirror which added that his son Joseph was resident engineer at Bristol Docks.

The scope of the projects with which he was concerned was incredible and few civil engineers matched his expertise in such a variety of fields.

A B George

JOHN STRINGFELLOW 1799–1883

Mechanical Engineer and Inventor

Entering the town of Chard, on the borders of Devon and Somerset, you are welcomed with the signs 'Chard, Birthplace of Powered Flight'. This surprises many who thought Kitty Hawk, North Carolina, where the Wright brothers flights in 1903 occurred, was the scene of the earliest powered flights. Chard's rightful claim rests on the inspired work of John Stringfellow.

Born near Sheffield in the middle of the industrial revolution, he was to see at first hand the many exciting developments that were changing the world at that time. Early in his life his family moved to Nottingham, a centre of machine lace making and where his father found work. As a teenager he was apprenticed to a lace maker during which time he found and developed the skills of a mechanic and engineer inherited from his father. He developed a particular interest in the design and manufacture of the bobbins and their holders that were used to carry the threads used in making the lace. Since just one loom needed hundreds of these bobbins, all subjected to wear and breakage, there would be a constant need for replacements and building a factory close to the mills purely to make bobbins would be a shrewd move.

At this time industry was going through a great upheaval. In the mid 1700's mechanical power was limited to three sources, man-power, horsepower and waterpower and it was the last of these that Stringfellow would have been most familiar with. However, steam was being harnessed and one of the first engines developed by John Watt in the 1760's featured a horizontal beam pivoted at its centre to create a vertical reciprocating motion at its ends. By the late 1700's the engine of James Watt had finally been made to rotate a shaft and then, by the turn of the century, as Watt's protective patents ran out engineers such as the Cornishman John Trevithick with his high pressure steam were making advances in the use of this form of power with its high efficiency.

Hand in hand with these developments came the mechanisation of many industrial processes but these improvements did not always receive universal acclaim. Millworkers smashed many machines that they thought threatened their jobs. These 'Luddite' activities prompted some of the lace mill owners to move from Nottingham to more rural surroundings such as Chard and this was where Stringfellow set up his factory in 1831 to make lace bobbins and their carriers.

Shortly after arriving in Somerset he married a local girl Hannah Keetch. For nearly all their lives together they lived in a house on the main street of Chard where they raised a family of twelve, nine of whom reached maturity.

A major use for the abundant power of steam was for transport. John Trevithick had a steam carriage running on the roads in 1800 and not many years later Brunel, among others, had steam driven ships travelling great distances. The two means of transport over land and over sea had been conquered by the power of machines. But man had also long dreamed of flying through the air as birds do. One of the first, in fiction at least, was the god Icarus whose avian exploits were limited only by the quality of adhesive he used; he flew too close to the sun and his wings fell off! Leonardo da Vinci had many ideas on the subject of flight mostly using flapping wings but also exploring the helicopter principle.

Two popular magazines published at this time were 'Mechanics Magazine' and 'Magazine of Science' and they, together with other magazines and National newspapers, were ever-ready to publish accounts however wildly phrased of any inventor's proposal for flying machines, details of progress in construction and the subsequent flight testing. Readers' comments and advice filled many columns and it is difficult at times to separate fact from fiction or truth from mere fancy in all this newsprint.

It is known that Stringfellow had had an interest in flying machines since his childhood and with the security of a successful business he was able to put his ideas for manned flight into practice. It is possible that Stringfellow was influenced by the work of George Cayley who at the time of Stringfellow's birth was making quite large gliders. Cayley had a very scientific approach and was the first person to specify the forces of thrust, drag, lift and weight acting upon a flying machine. He recognised the importance of streamlining and weight distribution in the structures. Being aware of the advantage of camber on the top surface of a bird's wing he correctly supposed that this added stiffness when needed on the down-beat or when soaring. Whether Cayley appreciated that the cambered upper surface added to the lift of a wing is not known. Stringfellow experimented briefly with ornithopters but quickly realised that designing a working structure with flapping wings held too many problems and that adding power to fixed wing gliders held better chances of success to achieve sustained flight.

In 1840 Stringfellow met and formed a partnership with William Samuel Henson, another lace mill owner recently moved from Nottingham to Chard, and a talented inventor who had already made successful gliding machines at the time of their meeting. The machines so far made by both men had no built-in means of sustaining flight. An engine of some sort was required to make them a serious means of transport but there were few possible power sources available in the mid 1800's.

The steel spring or clockwork mechanism was tried on models with limited success. The hot air engine was available but even if it could have been made light enough the size of machine needed to generate sufficient power would have been disproportionate to the airframe. This left the steam engine. Anything resembling Stevenson's Rocket as used on the railways would of course have been out of the question but Stringfellow had put his fine engineering skills to good use in making several small lightweight and powerful high pressure steam engines. Further, the use of propellers to convert engine power into thrust had been made by others; this principle was not challenged until jet propulsion was developed.

As Henson and Stringfellow proceeded with designing and building small versions of a proposed man-carrying aircraft it was realised that others were interested in their efforts so they patented their designs to prevent them from being stolen. The provisional patents that were published in 1842 created great interest and in order to take advantage of this and generate some much needed working capital Henson and Stringfellow formed the Aerial Transit Company. The design of the first full size flying machine was published but such was the extravagence of the claims made about the size, power, load-carrying capability and range that the whole scheme was ridiculed in the press. The hoped-for cash investments did not come and the company quickly folded. Henson had taken the major role in the technical aspects of this enterprise which had left Stringfellow relatively free to follow his own interests. The two men drifted apart and all that is known of Henson's subsequent history is that he married and moved to join his family in America.

The flying machines as initially tested were by no means complete. It was appreciated that the most important things to get right were the weight of the engine and airframe relative to the size and lifting power of the wings. To assess the forces created by air moving over a surface at high speed Stringfellow travelled on an express train and experimented out of the window with a device that could measure these forces with the surface tilted at various angles. Until it could be shown that a particular aircraft design could maintain level or preferably slightly climbing flight there was no point in proceeding with arrangements for steering and controlling rates of ascent and descent.

To give the best chance of success, the overall weight of the models including fuel and water for the engine were kept to a minimum and launching tracks were made to ensure the craft was released in the most favourable way. The aircraft would sit on a wheeled carriage mounted on a wire track sloping slightly downwards. On reaching a block at the end of the wire track the carriage released the aircraft which, it was hoped, would then assume free flight. The sizes of the various aircraft made over the years ranged from 3.0 metres to 6.1 metres wingspan and a major problem in testing them was to find spaces sufficiently large and yet private enough to avoid the distraction of spectators. Sites ranged from disused factories to abandoned churches.

On one occasion testing was planned to be on an open piece of land a couple of miles outside Chard. The machine was taken to a nearby shed ready for tests at dawn the next day. Everything went well until craft and carriage reached the end of the track when both crashed to the ground. The extra weight caused by the morning dew on the wing surfaces and their consequent loss of shape had been overlooked.

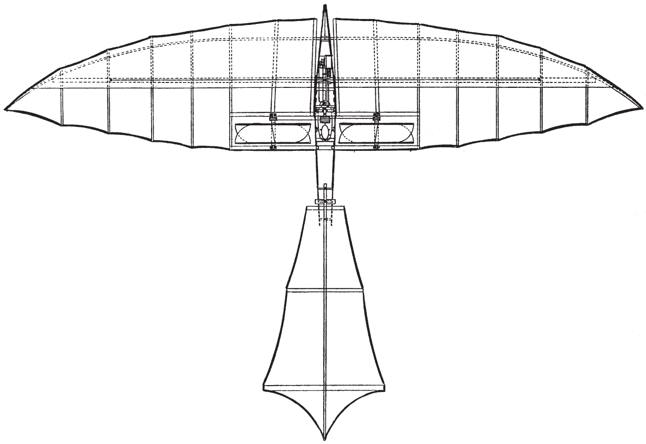
Stringfellow continued with his experimenting and between 1846 and 1848 completed the model that would truly fly. It was a monoplane weighing less than 4.1 kilogrammes with a wingspan of 3.0 metres having a total surface area 1.7 square metres . The silk covered wing was quite flat with the leading and trailing edges being smoothly curved. The tail member, also silk covered, was smoothly shaped but as no rudder was included the plane could not be steered, although the incidence of the tail could be adjusted to allow corrections to the flight path.

A steam engine was carried and two contra-rotating propellers 40.6 centimetres diameter each with 4 blades and mounted behind the wings were driven by pulley and cords from the engine. The engine incorporated a cylinder 1.9 centimetres in diameter with a 5.1 centimetre stroke driving the 6 groove pulley through a bevel gear. The water boiler was heated by a methylated spirit or naptha lamp.

To design and develop such a powerful steam engine light enough to be flown and also to construct an aeroplane capable of carrying it in flight was an incredible achievement by Stringfellow and a marvel of ingenuity.

The world's first successful powered flight was at Chard in a room 20 metres long by 3.7 metres high. On release from its carriage the model climbed at an inclination of 1:7 and flew 12 metres before being stopped by a suspended canvas sheet. In

STRINGFELLOW'S POWERED FLYING CRAFT



August 1848 the second demonstration occurred in Cremone Gardens, a pleasure park in Chelsea, London, when an impressive, climbing, stable flight of 37 metres was achieved. These powered flights, the first in the world, did not, however, command a great deal of attention at the time and it was not until many years later that the full significance of them was appreciated. Stringfellow may have been disappointed in this but his aspirations were always fixed more upon the attainment of success than upon the aquisition of fame and wealth.

He continued his work during the next few years and, although rather hit-and-miss in achieving longer sustained flight, had his greatest successes in 1868 with a model steam powered triplane capable of giving a better more controlled flight with a stronger more compact shape. It was said this craft possessed 'one third the power of a horse whilst its weight was that of a goose'. The engine was found to have the greatest power for its weight in a competition held by the Royal Aeronautical Society in the aeronautical exhibition at Crystal Palace, London. It won a prize of

£100 which he used for the construction of a building 21 metres long to continue his experiments. In the same year he was elected to the Royal Aeronautical Society.

Soon after this his sight began to fail and although maintaining an interest in flight he did not achieve further practical success. Stringfellow, even during the time he had an active interest in aircraft, was so inventive and mechanically skilled that he often had to call a halt to his main passion of flight in order to satisfy other business customers. He became proficient in the new art of photography, invented a wheeled shield that afforded protection to soldiers from bullets and made a device called a scarifier for the 'blood-letting' regarded by doctors as a cure for most diseases of the time. This comprised a cutting blade mounted on a handle together with a depth stop and a cup to collect and measure the blood taken from the patient. One order for these gadgets was for 300 units to be used in China.

John Stringfellow died in 1883 at the age of eighty four. He always had a cheerful and vigourous personality and was energetic, level-headed, painstaking and enthusiastic. He had the instincts of a man of science but backed these with practical experiments and must be considered a truly all-round engineer.

It is ironic to consider that in 1867, the year before Stringfellow's greatest success, Nikolaus Otto had invented the four stroke cycle and the internal combustion engine. If those two men had met there is the possibility the Wright brothers' achievements of man-carrying flight would have been pre-dated by some thirty years.

G A Briggs

PERCY CARLYLE GILCHRIST

1851–1935

Chemist and Metallurgist

On the Marine Parade at Lyme Regis, Dorset stands a group of attractive thatched cottages that look out over Lyme Bay. It was here at Harville Cottage, the house of Thomas Clarke, a retired Master Mariner, that Percy Carlyle Gilchrist was born on 27 December, 1851. His mother Anne (nee Burrows) was from an upper class family and she and her barrister husband Alexander were of independent means sharing the same writing, scholarly and intellectual interests. Alex chose not to practice as a lawyer and instead he pursued his life-long ambition of becoming a writer. The early years of the marriage were nomadic ones, spent travelling the country in search of information for the book Alex was writing. Two years after Percy was born they made their first home in an old manor house in Guildford.

Three more children were born to the Gilchrists who by 1856 had settled in Cheyne Row, London, but in 1861 Percy contracted scarlet fever which, in those days, was a life-threatening disease. Through contact with his son, Alex also contracted the disease to which he succumbed. With four children to support, Anne continued with her writing while Percy attended Felsted School, Essex, where he displayed an interest in the sciences. From Felsted he studied at the Royal School of Mines, South Kensington where he became a Murchison Medallist and obtained his associateship of that school three years later. He also became a member of both the Institution of Civil Engineers and the Institution of Mechanical Engineers. In 1877 Percy married Norah Fitzmaurice, the daughter of Captain L N Fitzmaurice, RN, by whom he had a son Alexander, and a daughter Ellen.

Until the middle of the eighteenth century cast iron was the most common metal used in construction work but it contained a large number of impurities that made it brittle and liable to failure under stress. Removal of these impurities from the iron was a difficult process but when completed, it produced wrought iron that was softer and easier to work. However, both cast and wrought iron were prone to contain blowholes created during the casting process which made them unable to withstand strong tensile forces and it was this structural weakness that contributed to the disastrous failure of the Tay Bridge in 1879. By introducing carbon into the iron, steel could be created, a metal that was strong, flexible and durable, possessing all the qualities of cast and wrought iron but also capable of resisting high tensile forces. However, the process was difficult and expensive until Henry, later Sir Henry, Bessemer designed his converter.

Steel was produced in the Bessemer converter from impure pig iron smelted from the basic ores but sadly, it was not the perfect answer and frequently produced steel that was of poor quality and sometimes quite useless. The reason for this was eventually found to be the presence of the phosphorous that remained in the steel and which the converter had failed to remove. The most phosphorous-free ore in this country was the rich haematite discovered along the coast of Cumbria that led to the establishment of iron and steelworks in the region, the largest of which was at Barrow-in-Furness. But the deposits were limited and expensive to extract, consequently ore speculators moved to Spain where cheaper material was available.

After qualifying at the Royal School of Mines, Percy Gilchrist took up a post of analytical chemist at Cwm Avon Ironworks in South Wales and it was at this time that he was approached by his cousin Sydney Gilchrist Thomas, about a theory the latter had developed for eliminating phosphorous from Bessemer steel.

Sydney Gilchrist Thomas who was about nine months older than his cousin, was a remarkable man. Due to financial difficulties following the early death of his father, he was forced to abandon his dream of studying medicine and instead, become a clerk in the Metropolitan Police Courts. But his real interest lay in chemistry which he studied with dedication in his spare time. While attending a course of lectures at the Birkbeck Institution he became fascinated in a particular lecture that referred to the scarcity of low phosphoric ores in the steel manufacturing industry. Mr George Chaloner, a lecturer in inorganic chemistry and metallurgy, stated that 'the man who succeeds in eliminating phosphorous in the Bessemer converter would one day make his fortune' and it was this remark that fired the imagination of the young Sydney Thomas. Thereafter he dedicated himself to the study of the problem that eventually led to the discovery of a process that became known as the Thomas-Gilchrist Process and for which he and his cousin Percy became famous.

In due course, Sydney Thomas also qualified as a chemist, but whilst still a clerk to the police court, he pursued his investigations by converting a room in his house into a makeshift laboratory where he undertook experimental work. However, the conditions were far from satisfactory and quite dangerous.

He was encouraged in his research by Chaloner at the Birkbeck Institution but being unable to carry out full-scale tests in a converter, Sydney wrote to his cousin explaining his theory and setting out the lines on which it could be tested.

Initially Percy Gilchrist was sceptical about his cousin's work and having just obtained a new post at the Blaenavon Works, he was reluctant to get involved in unofficial experiments. Consequently the experimental work was slow to start. But Sydney's enthusiasm gradually infected Percy and following a further meeting between the two, it was agreed that experimental work would commence, financed by Sydney Thomas out of his meagre salary. Gilchrist started the work in a rough shed on a mountainside but little was done until 1877 when the experiments began in earnest. As Gilchrist began to anticipate the success of the experiments the work advanced quite quickly, necessitating

Sydney Thomas's more active co-operation; this required him to make frequent trips to Wales on the days he was off duty.

Similar work was proceeding without success on the continent and in America but the work that Percy Gilchrist was carrying out did not go unnoticed by E P Martin, the manager of the Blaenavon Works who became convinced that Gilchrist and Thomas were working on the right lines. He was so impressed with the results of their experiments that he arranged to relieve the cousins of their pressing financial worries by agreeing to buy shares in the patents for which they had applied, and to provide facilities for their research work to continue.

Details of Gilchrist and Thomas's work were presented for discussion at various meetings of learned institutions at home and overseas but their claims to have devised a process for successfully removing phosphorous from the Bessemer converter were met with scepticism and a certain amount of incredulity. However, a manager of a steelworks in Middlesbrough decided to pursue the matter and visited Blaenavon where he arranged for further tests that convinced him the dephosphorisation process was a commercial possibility. When the results of the successful tests became known Gilchrist and Thomas were besieged by steel manufacturers wishing to obtain the patent rights and their financial future was assured.

Sydney Thomas resigned his position at the police court and devoted himself to promoting the new process as well as negotiating patents and contracts with home and overseas manufacturers. New companies were formed of which the cousins were shareholders and Sydney travelled widely at home and abroad in connection with the work. Sadly he had never enjoyed good health and the strain of his early work, coupled with the extensive travelling soon took its toll. He spent the last few years of his life working on a project for converting the waste slag from the Bessemer converters with its high phosphate content into a basic fertilizer. He died, not yet thirty five years old, having made a fortune but not living to see basic slag become the highly valued fertilizer he had forecast.

Honours were bestowed on both men who were awarded the gold medal of the Society of Arts and the Bessemer Medal of the Iron and Steel Institute.

Percy Gilchrist moved with his family to Redcar where he continued his work in the steel industry as the managing director of the Dephosphorising and Basic Patents Company Ltd., a company originally established to protect the rights of the process he and his cousin had developed. He was also associated with other companies in the steel industry.

The Thomas-Gilchrist process was taken up actively on the continent and was duly extended to the Siemens open-hearth process but for some reason, it gradually ceased to be employed in this country until its revival by a British firm in the mid-1930's. Percy Gilchrist may not have been aware of this for after along illness, he died on 15 December, 1935 some fifty years after his cousin with whom he had revolutionized the steel manufacturing process.

Since his death improvements have taken place in the process and although historically Gilchrist has been overshadowed by the figure of Thomas, there is no doubt that Percy's contribution to the invention of the basic process was just as great. He was the practical chemist and metallurgist who proved by experiment what his cousin had developed in theory. He was a member of the Iron and Steel Institute, of which he became Vice President, for sixty years and was elected a Fellow of the Royal Society in 1891, an honour that surely would have been bestowed also on his cousin had he lived.

An obelisk erected on the site of the Blaenavon Ironworks in Monmouthshire commemorates the experiments carried out by Gilchrist and Thomas and the Retired Chartered Engineers' Club, Exeter has fixed a plaque on the esplanade at Lyme Regis to record Gilchrist's birth in the town.

This chapter embraces the combined work of both Thomas and Gilchrist and shows that success also can be achieved by independent dedication and hard work. Today we have cranes that could lift the Eiffel Tower, buildings that soar 800 metres skywards and vessels of 500,000 tonnes travelling the oceans, all as a result of their pioneering work in developing the steel manufacturing process. Sydney Thomas had the dream that Percy Gilchrist made come true with the result that both men are equally revered in the annals of steel manufacture.

A G Banks

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!

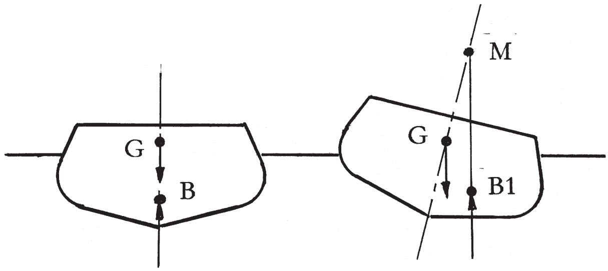
The friendship established between Froude and Brunel whilst Froude was working on the Bristol to Exeter railway continued after his 'retirement', Brunel seeking his advice on a number of occasions. Froude designed an improved seal for the tubes on the South Devon Atmospheric Railway between Exeter and 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

VESSEL STABILITY



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.

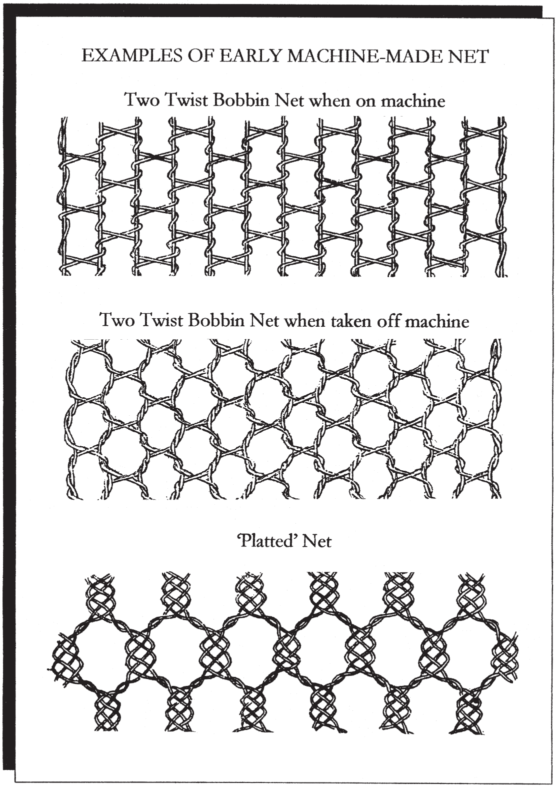
On completion of his apprenticeship he moved to Nottingham to work for another framesmith building knitting machines where his skills soon commanded a high wage. His employer very quickly assessed Heathcoat as 'inventive, persevering, undaunted by difficulty or mistakes, patient, and having great self-confidence'.

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

JOHN LETHBRIDGE 1675–1759

Inventor and Diver

It is a special kind of individual who, at the age of 39 living in a comfortable home with a caring wife and large family, sets out for the dangerous life of a world-travelling treasurer-seeking sea diver. Such an individual was the inspiring character John Lethbridge.

His early upbringing was in and around the hamlet of Wolborough, near Newton Abbot. A member of the well respected Lethbridge family he was a trustee of endowed parish property in that hamlet and became established as a wool trader in Newton Abbot. Unfortunately, the decline of the wool trade in Devon created serious financial problems so he started thinking about other ways to make a living. In his own words: 'Necessity is the parent of invention, and being in the year 1715 quite reduced, and having a large family, my thoughts turned upon some extraordinary method to retrieve my misfortunes, and was prepossesed that it might be practicable to contrive a machine to recover wrecks lost in the sea'.

Why he should have decided on a sea faring venture is not entirely clear; perhaps it was because he lived in a county fortunate enough to have the open sea on two borders and with excellent ports. Considerable sea trade existed to the Americas, Africa and China through the towns of Plymouth, Dartmouth and Brixham so tales of shipwrecks must have been told throughout the county. It is possible that these stories influenced his idea of salvaging valuable cargo from sunken vessels.

Lethbridge started his new venture with a couple of experiments. Perhaps for dramatic effect, he arranged the first to take place at noon on the day of a solar eclipse. In his own words: '. . . and the first [step] I took towards it [the new venture] was going down into a hogshead [barrel], upon land, bunged up tight, where I stayed half an hour without communication of air'.

The scene must have been strange. An orchard with a collection of friends and neighbours, nervous in the eerie swiftly gathering darkness of the eclipse, sitting around a large barrel with Lethbridge inside. The sunshine reappeared as they heard a knock on the wood and relieved friends released him. The diving engine inventor had made his first experiment to discover how long he could survive in a closed space without replacement of his air supply.

The next experiment was to test his ability to remain encased in the barrel under water. Described again in his own words: '. . . then I made a trench near a well, at the bottom of my orchard in this place in order to convey a sufficient quantity of water to cover the hogshead, and then try'd how long I could live under water without air pipe or communication of air'. Encouraged by the surprising fact that he could remain longer under water than on dry land, Lethbridge then designed what he called his diving engine and commissioned a well known London cooper to construct it as follows: '. . . perfectly round, about 6 feet in length, about 2 and a half feet diameter at the head, and about 18 inches at the foot . . . iron hoops . . . to guard against pressure . . . there are two holes for the arms, and a glass about 4 inches diameter . . . to look through . . . in direct line with the eye, two airholes . . . into one of which is conveyed air by a pair of bellows before going down to the bottom'. With this apparatus lowered from the side of a ship so he was in a horizontal position, Lethbridge believed he could work at water depths to 18 metres for periods of about thirty minutes before being hauled to the surface for the air to be replenished by bellows connected to one of the two air holes.

Diving for sunken treasure was not a new activity at this time. Previous years had seen the appearance of various forms of diving bells, weighted casks and submarine boats with air systems. Even at the time Lethbridge was experimenting in Devon, a Major Becker was reported to be demonstrating his engine made from leather and glass by walking three quarters of a mile along the bottom of the River Thames in London.

There were individuals who had obtained patents for their ideas and a claim was made by a Mr Symonds of Harbertonford that he had invented an engine similar to Lethbridge's and demonstrated it on the River Dart. Lethbridge was adamant that he had no knowledge of the Symond's design.

It was however remiss of Lethbridge not to have registered his invention since it was designed to be used without the emcumbrance of piped air and specifically for retrieving articles from the sea bed. Of all the other inventions, none has been reported as helping to achieve such great financial rewards.

He demonstrated his engine for many years but, despite his entreprenarial character and spirit, work contracts eluded him; no doubt because he had no boat, no knowledge of sea faring and no personal connections with individuals influential in the business on which he was embarking. However, after a prolonged and succesful demonstration of his skills to directors of the English East India Company he met Jacob Rowe, an experienced diver and the owner of a patent for similar equipment.

They went together to the Isle of May to dive onto the English East Indiaman Vansittart which had sunk at an extemely dangerous site below the edge of a reef with immense surf. Lying in a prone position with his arms sealed by leather sleeves protruding through the wooden wall of his engine, breathing increasingly stale air with water slowly seeping in, buffeted by currents and surf breaking overhead, working conditions were abysmal. He often laboured for six hours moving about in a twelve foot square retrieving items from the sea bed, blasting with primitive underwater explosives when needed, the only communication with the surface ship by a signal rope on which he tugged coded commands. If he had been trapped in the sunken wreck's rigging or by rocks, nothing could have saved his life. In the words of his grandson: 'He was a man highly esteemed for honour and integrity . . . no Danger ever annoyed him whilst he was at work on the wreck of a ship with water up to his Chin'.

A year later Lethbridge and Rowe returned to London with a vast treasure from Vansittart including 27 chests of silver. This was shared out by the Master of the Royal Mint, Sir Isaac Newton, and the fortune enabled Lethbridge to set off on his own to explore the wreck of the Royal Anne off Lizard Point, Cornwall.

News of the venture came to the attention of the directors of the Dutch East India Company who had suffered severe losses through recent shipwrecks; in particular they were anxious to salvage treasures lost in Table Bay, Cape Town, South Africa. After lengthy negotiations a contract was signed in Holland and work commenced. Unfortunately the operation was unsuccesful mainly because of shifting sandbanks obscuring the sunken cargo.

At about this time, the Company received news that the vessel Slot ter Hoge [Castle of Hooge] was wrecked at the island of Porto Santo [now named Porto do Guilherme], Madeira, in the Atlantic ocean. A salvaging contract in 1725 with Lethbridge agreed he would receive a basic fee of ten pounds per month plus expenses plus bonuses to be left 'to the generosity of the Directors'. Lethbridge sailed to the sheltered bay there and with a team of divers achieved great success retrieving the treasures.

They then returned to Table Bay for further attempts at that site because the Company attached great importance to this operation. All the divers were treated with much respect, being offered the best food, liquor to help them perform the arduous task; accommodation was provided in The Castle used by the Governor!

Then followed a series of profitable ventures before Lethbridge sailed home to be with his family in 1728. He suffered illness but four years later returned to the Slot ter Hoge site for more exploration. Tragically Ellen his wife died the following year. More work took him to Marseilles, Southern France and then again to the wreck in Porto Santo; unfortunately, illness thwarted his ambition to complete the site final clearance of the Slot ter

Hoge. This vessel was explored recently by marine archaeologist and veteran salvage diver Robert Stenuit with a team who were intrigued with, and admired, John Lethbridge's life and exploits. They were able to recover items and silver bars worth a fortune!

Incredibly, at the age of eighty one, he applied for a contract from the English East India Company to salvage the vessel Dodington, sunk on Bird Island, Algoa Bay, off the coast of South Africa on a jagged inlet smashed by breaking surf and surrounded by sharks. It is likely that Lethbridge anticipated his involvement in this venture as organising the logistics rather than physical work but this demonstrates again his extraordinary tenacity and courage. The operation was considered too dangerous by the Company and he received no contract.

His amazing career ended and he retired. He had worked on the wrecks of some sixteen vessels, all lost in the space of twenty years and his achievements funded the purchase the estate of Odicknoll, Kingskerswell, near Wolborough, allowing his family to live in considerable comfort. The diving engine was last observed in grounds belonging to Holdsworth, the last Governor of Dartmouth but a replica of it exists to this day.

The Wolborough Parish Register records Lethbridge's burial on 11 December 1759 with the words:

'Mr John Lethbridge the Elder, Inventor of
a most famous Diving Engine
by which He Recovered from the Bottom of the Sea
in different Parts of the Globe
almost an Hundred Thousand Pounds for the
English and Dutch Merchants
which had been lost by Shipwreck . . .'

Modern-day diving techniques with sophisticated equipment allow safe and efficient robot operations to depths exceeding 6,000 metres. The sea-going vessel 'MV John Lethbridge' was extensively refitted in 2005 at Falmouth for SubSea Resources PLC and is being used for underwater exploration. There are published lists identifying tens of thousands of wreck sites with hundreds of millions of pounds worth of sunken cargo. Most treasure is owned by governments or insurers but generally 90 percent of the value is awarded to those who, like John Lethbridge, have the courage to retrieve it.

J A Knivett

JOSEPH WHIDBEY 1755–1833

Marine Engineer

Most Devonians will be aware of the stone breakwater across the entrance to Plymouth Sound, and some may have benefited, on returning from voyages in craft large and small, from the shelter it provides from the stormy seas outside. Perhaps fewer realize that the breakwater was constructed during the Napoleonic wars nearly two hundred years ago to provide shelter for the British fleet from violent storms on an otherwise unprotected coast. Although, as in all engineering projects, many people were involved in the implementation of the breakwater project, the man principally involved in its planning and construction was Joseph Whidbey.

Joseph Whidbey rose from obscurity – his place of birth and the circumstances of early years widely unknown – to become a Fellow of the Royal Society and one of the leading engineers of his day. In the eighteenth century there was, of course, no formal training or accepted apprenticeship for becoming an engineer, but the position of Master of one of His Majesty's ships was perhaps one of the more unusual steppingstones to an engineering career. At that time the Master on a ship of the Royal Navy was the senior non-commissioned officer responsible for sailing and navigation, perhaps equivalent to a warrant officer today. In 1786 Whidbey was Master of the Europa then stationed in the Caribbean under its Captain George Vancouver, when they were ordered to undertake a survey of the entrance to Port Royal harbour in Jamaica. The two men co-operated on the work. In view of its accuracy, the resulting chart was considered to be a model of hydrographic survey work. It was later published under their joint names. In 1791 Vancouver was appointed to undertake surveys of the north-west coast of North America, and Whidbey sailed with him as Master of his ship Discovery. Their joint work on hydrographic surveys of the north-west coast, which lasted until 1794, was well received by the Admiralty and the scientific community, and it was at this time a friendship was established between Whidbey and Sir Joseph Banks, President of the Royal Society, who considered that Whidbey was mainly responsible for the success of the work on the north-west coast. During his time with Vancouver, much of it spent in small boats surveying the creeks and inlets of the American coast, Whidbey learnt much about good anchorages and the protection of ships from storms, which he was able to put to good use during his subsequent career.

On his return from America, Vancouver recommended Whidbey for promotion to rank of Master Attendant. In 1799, as Master Attendant at the Sheerness dockyard, Whidbey was responsible for the salvage of a Dutch frigate lying in 9.8 metres of water on the Great Nore in the Thames Estuary. The salvage of the vessel was considered to be a major achievement, and, encouraged by Sir Joseph Banks, Whidbey presented a paper on the salvage work to the Royal Society in 1803. In the same year Admiral Lord St Vincent, another member of the Royal Society, commissioned Whidbey to undertake a survey of Torbay with a view to finding a safe anchorage for the Channel Fleet. Lord St Vincent, who during the succeeding years was at various times First Lord of the Admiralty and Commander in Chief of the Channel Fleet, was concerned at the vulnerability of the fleet to storms along the south west coast, especially in time of war. This was Whidbey's first visit to Devon where he was to spend much of his working life over the next thirty years. The published chart resulting from Whidbey's surveys indicates an area in the middle of the bay as the site for an artificial island to provide protection for ships in the bay from rough weather. Nothing resulted from this work, but Lord St Vincent continued to be concerned at the lack of a safe refuge for the fleet and concluded that Plymouth might make a better anchorage than Torbay. In 1806, his colleagues in the Admiralty having been similarly persuaded, Whidbey, along with the respected engineer John Rennie, was asked to undertake a similar survey in Plymouth Sound.

Whidbey had worked with Rennie in 1804, after being transferred from Sheerness to Woolwich, where silting was a problem, and he may have known him earlier. John Rennie, was a civil engineer with experience of bridge construction as well as harbour and river works. He had been called in by the Admiralty to advise on how the silting problem at Woolwich might be overcome, and dredging costs reduced. Rennie appears to have appreciated Whidbey's wide practical experience in marine matters and, along with Sir Joseph Banks, proposed Whidbey for election as a fellow of the Royal Society in 1805.

Rennie and Whidbey, accompanied by Samuel Hemas, Master Attendant at Chatham, who was also familiar with the Plymouth area, visited Plymouth in March 1806 at the time of high spring tides, and, advised of the urgency by Lord St Vincent, submitted their report to the Admiralty a month later. This recommended that an artificial island about a mile long built of stone rubble should be formed in the centre of the Sound over the shallows occurring at the Shovel rocks, without obstructing the existing channels nearer to the shore on either side. The alternative of breakwaters running from the shore on either side was discounted because they would indeed tend to obstruct the existing channels. It was estimated that the work would require two million tons of rock and cost about £1 million. In discussions that followed, it was strongly recommended that Whidbey should be appointed to superintend the work. However, although the admirals were keen for the work to proceed, it was a time when Britain's fortunes in the war with France were at a low ebb and the government, conscious, then as now, of the many calls on its limited resources, felt it could not afford the high cost. The project was shelved.

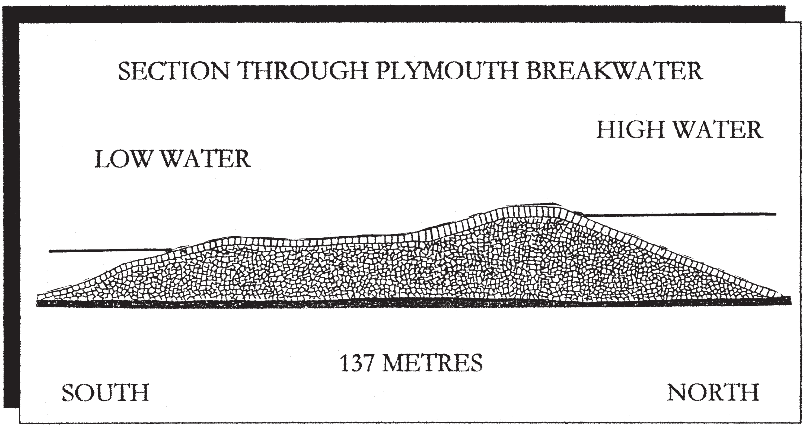
Over the next few years Whidbey remained at his post at the Woolwich dockyard and continued to liaise with Rennie regarding the silting problem there. He attended meetings at the Royal

Society and, amongst others, corresponded with Lord St Vincent. Meanwhile, behind the scenes, the Admiralty, ever conscious of the lack of a safe anchorage for the Channel Fleet, continued to press the Government to allow the breakwater project to proceed. Britain's fortunes in the war with France gradually improved and, finally, in January 1811 the go-ahead was given. The project was to follow the plan proposed previously by Messrs Rennie & Whidbey and be carried out under the superintendence of Whidbey. Extra funds were included in the Naval estimates and the work was to proceed with all urgency.

Whidbey arrived in Plymouth in August 1811, which was to be his home for the next nineteen years. The first thing to be done was to negotiate with the landowner, the Duke of Bedford, for access to the proposed quarry site at Oreston This was chosen for its good limestone rock and because of its proximity to deep-water in the shelter of the Cattewater. Rennie and Whidbey designed a special vessel for carrying the heaviest rocks, which were loaded onto trucks and run aboard on rails. On arrival at the breakwater site, the rocks were discharged from their trucks over the stern. With an upper and lower deck and two tracks on each deck, about twenty-four 5-tonne rocks could be carried. Eventually, ten vessels of this type were brought into use. To ensure that the rocks could be discharged in the required positions, Whidbey set out the site early in 1812, fixing marker and mooring buoys at strategic points. Work also started on opening the quarries, building the loading berths on the Cattewater and laying a railway between the two. Separate contracts were let for quarrying the rock and for transporting it to the breakwater site. William Stuart was appointed resident engineer overseeing the work at the quarry site. The Prince Regent's birthday, 8 August, was chosen for the official starting date, when a 7-tonne rock was discharged from the stern of the first specially-designed vessel to the accompaniment of music and in the presence of 2,000 spectators.

The work of excavating, transporting and discharging rock at the breakwater site continued apace. By 1813 the mound became visible at low water and in the following year the length above water level was sufficiently extensive to allow ships to anchor in its lee. The approved design allowed for seaward slope of 1:3 (one length vertical to three lengths horizontal), although Rennie had favoured a slope of 1:5. In those days, there were no design charts and tables, as now, relating rock size, slope and wave height, so the slope chosen depended upon the experience of the engineer. Whidbey considered that the steeper slope would be adequate. In 1817, however, a violent storm washed much of the rock from the seaward side over the crest, leaving a seaward slope of about 1:5. Despite this, and a recommendation from Rennie that the plan should be modified to provide a 1:5 seaward slope, Whidbey, supported by the Admiralty on grounds of cost, continued to adhere to the original plan, until once again the mound was reconfigured by a hurricane in November 1824. Rennie and other leading engineers were called in to assess the damage. They proposed modifying the design to provide a 1:5 seaward slope, faced with coursed granite masonry above low water level, needing over half a million tons of additional rock.

Although Rennie had a major influence on the design, his role was that of advisor rather than Engineer, in the manner that became the practice later in the nineteenth century and continued almost to the present day, where a client wishing to implement a project would appoint an Engineer to advise on the optimum scheme, prepare detailed designs, award contracts and supervise



construction. Whidbey, as an employee of the Admiralty, was in charge of the setting out and construction of the work, directing progress and letting and supervising contracts for the excavation and transport of rock. Soon after arriving in Plymouth Whidbey established his home and site office at Bovisand Lodge overlooking the Sound and the site of the breakwater construction from the east. From a jetty below his house he could board his yacht Nonnio and be on site within half an hour. He was paid a salary of £1,000 per year plus expenses, a handsome sum at a time when a gentleman could live comfortably, if not extravagantly, on £300 a year.

Although Whidbey may have been wrong in his belief that a 1:3 rock slope would withstand the onslaught of winter storms, he was much esteemed by his colleagues in the engineering and scientific community for his sound common sense, backed up by much practical experience gained both during his time surveying on the coasts of north-west America and at Sheerness and Woolwich. In 1809 he was elected an Honorary Member of the Society of Civil Engineers, which indicated perhaps that his colleagues, while appreciating his contribution to engineering, still did not consider him a true engineer. In 1822, however, he was transferred to the class of Ordinary Member, indicating that his apprenticeship was over! Whidbey's work in calming the waters in Plymouth Sound was much appreciated by the citizens of Plymouth, and in 1814 he was made a Freeman of the City.

Apart from his work at Plymouth, in the 1820s Whidbey was consulted about a number of harbour improvements elsewhere, including at St Ives and Ilfracombe in Devon and further afield at Whitehaven and for the Port of Glasgow and the River Clyde. In 1822 the idea of a breakwater in Torbay was revived and Whidbey and Stuart carried out a survey and prepared cost estimates for the Admiralty, but again the scheme did not proceed.

Whidbey remained in charge of the breakwater works for nearly 20 years. He retired in 1830, and William Stuart took over the supervision of the works. The strength of the revised design with 1:5 seaward slope was proved in a fierce storm in October 1836, which the breakwater withstood with a minimum of damage. Completion work, including the construction of a lighthouse at the seaward end, continued until 1865, the total cost of the work then being a little short of £1.5 million.

After his retirement Whidbey moved to Taunton, where he died in 1833 and where his tomb can still be seen in St James's churchyard. Whidbey's portrait by the artist J Posford hangs today in the London headquarters of the Institution of Civil Engineers, along with the portraits of other distinguished engineers.

M C D La Touche

ALFRED JAMES SIMS 1907–1977

Warship Designer and Submarine Expert

Alfred Sims, who became the first Director General Ships and Head of the Royal Corps of Naval Constructors, had a modest start to life. He was the youngest of five children and was born in the Devon village of Revelstoke, near Plymouth, on 11 October 1907 where his father was the maintenance engineer on the local estate of Lord Revelstoke. In due course he attended Regent Street Higher Elementary School in Plymouth and at the age of fifteen he entered the Royal Dockyard, Devonport as an Electrical Fitter Apprentice, transferring to a Shipwright Apprenticeship two years later.

In the early twentieth century it was virtually impossible for a lower middle class boy to attend University but a Dockyard apprenticeship offered a good education and a satisfactory career to those young men who were able to pass the entrance examination. Alfred Sims duly took the examination and passed top of his intake.

The Royal Dockyard schools were unique with their training and education. At the end of the first year, half the boys went into craft training whilst the remainder carried on with their academic education. A similar elimination was repeated at the end of the second and of the third year. Accordingly, those apprentices who completed the fourth year were the cream of the original intake (and many in later years wore a numeral 4 badge on their lapel to denote their achievement). Again, Alfred Sims was top of his intake and in 1928 won a Cadetship to the Royal Corps of Naval Constructors.

This award was given only to very few apprentices from the nationwide Royal Dockyards and in effect set the ex-apprentices on a professional engineering career. Sims, together with the other new entrants to the RCNC, was sent to the Royal Naval College, Greenwich to study naval architecture, during which time, although a member of a civilian organization, he wore a Royal Naval officer's uniform. Again, he passed out as top of his entry in 1931 with an outstanding First Class Professional Certificate. As was the custom, he then spent a year at sea, still in naval uniform, gaining experience in various ships of the Mediterranean Fleet before being appointed to Chatham Dockyard.

Sims spent four years at the Royal Dockyard, Chatham as an Assistant Constructor where he was in charge of submarine construction, supervised the drawing office and carried out pioneering work on the application of welding in warship construction. During the latter part of that appointment he was the lecturer in Naval Architecture at the Chatham Royal Dockyard School.

In 1936, he joined the Admiralty in the Naval Construction Department. He worked with the Submarine Design Group on the Triton Class submarine. For the rest of his career he continued to have a particular, and increasingly important, association with submarine design, construction and operation. In 1938, he was appointed to the Staff of Rear Admiral Submarines in the rank of Constructor Lieutenant Commander, shortly afterwards being promoted to Constructor Commander. This was a very early promotion to senior rank.

In 1940, Admiral Max Horton, was appointed Flag Officer Commanding Submarines, Gosport and a close wartime association began between the two experts. Sims moved with Admiral Max Horton and his staff to London early in the war, and remained with him when the Admiral was appointed Commander-in-Chief, Western Approaches. In this appointment, Admiral Max Horton was responsible for the transatlantic convoy system. Sims advised him on anti-submarine warfare, and on submarine construction.

During this period he won the respect of those serving at sea for his dedication to the Service and for fostering a good relationship between those bearing the brunt of the war and those who were working to produce better submarines. He was also commended for his work in re-structuring captured German equipment. For this dedicated, and essential work, he was awarded an OBE in 1943. A year later, due to his versatility, he was sent to the Far East to investigate 'The Habitability of Naval ships under Wartime Conditions'. This was in anticipation of the eventual swing of resources to the war against Japan in the Far East and the formulation of a policy for air conditioning ships of the Royal Navy. He afterwards wrote the first edition of the Ventilation Manual, which became invaluable to later designers.

Then in 1944, when he was only thirty seven years of age, he was sent to the Admiralty at Bath, as a very young Chief Constructor in charge of submarine design and building. In 1947, he produced a paper for the Institute of Naval Architects on 'British submarine design during the war'. He had by then established his position as the principal authority on submarine design in the United Kingdom.

With the coming of peace, the training of Naval Constructors returned in the Autumn of 1947 to the Royal Naval College, Greenwich. With his outstanding academic record and experience in senior appointments, Sims was the natural selection to become the first post-war Professor of Naval Architecture. Much needed to be done to bring the course up to date. Wartime experiences and great technological advances demanded a complete re-think on warship construction and during his five years in the chair Professor Sims completely re-wrote the syllabus and the course notes. His students from that time recall his dedication to the task and the late hours he spent preparing his material. He expected the same dedication and determination from his students, one saying that you 'either loved him or hated him'. He alone was responsible for returning the Greenwich course to its pre-eminence amongst schools of naval architecture in Britain and was the mentor for a fresh generation of naval architects, many of whom later served, with distinction, under him at the Admiralty at Bath.

By 1952, after completion of five years as Professor of Naval Architecture and the inauguration of a completely re-designed course, Alfred Sims was able to hand over his chair and return to the Admiralty at Bath. He was put in charge of the section responsible for aircraft carrier design and was particularly concerned with the completion of the aircraft carriers HMS Ark Royal and Hermes together with the extensive modernization of HMS Victorious. A year later he was promoted to Assistant Director and submarine construction and design were added to his responsibilities. He held this post until 1958. Sims had come to the forefront of his profession at, for him, a most favourable time.

The post war period was a critical time for the Royal Navy. After six years of war the Fleet was in poor shape and overtaken by technical advances, particularly in electronic warfare, weapon systems and ship propulsion. Most ships were of pre-war design. It had been shown that battleships and large cruisers with their heavy gunnery were obsolete and that the future strength of the Navy lay in aircraft carriers, frigates and submarines. Because of his experience, Alfred Sims was the ideal man to control and influence the design and build of the post-war submarine fleet.

The Admiralty was early in appreciating the advantages of nuclear propulsion, and in particular its application to submarines which until then been limited in speed and range. Frequent surfacing for air was necessary to recharge batteries and nuclear power appeared to offer the chance of speeds in excess of 25 knots (28.8 miles per hour) with unlimited endurance. Study teams were formed in the early 1950's with the aim of having a nuclear powered submarine by mid 1962. In 1956 a draft Staff Requirement for a nuclear submarine was agreed and the following year the United States offered to release nuclear information.

Then in January 1958 the President and the Prime Minister signed an agreement for the United Kingdom to purchase a complete nuclear propulsion plant. This opened the way for

Britain's first nuclear powered submarine (S101), later to be known as HMS Dreadnought. This ship was designed at the Admiralty at Bath by a team under the overall direction of Alfred Sims, built at Vickers Shipyard, Barrow on Furness and launched by Her Majesty the Queen on Trafalgar Day 1960. She was completed on time and on cost.

In 1957 an extensive enquiry into the organization of the departments of the Controller of the Navy was carried out. The committee recommended that these various departments should be formed into three separate units responsible for Ships, Weapons and Aircraft respectively and that each should be headed by a Director General. Alfred Sims was chosen to become the first Director General Ships, and he spent an intensive period from April to October 1958 preparing the terms of reference and working practices of the new organization.

In October 1958 he took up his new post, becoming responsible to the Admiralty Board for the old departments of Naval Construction, Engineer-in-Chief of the Navy, Electrical Engineering and Naval Equipment. At the same time he became Head of the Royal Corps of Naval Constructors. He had not only reached the top of his own profession but also had assumed responsibility for other engineering disciplines within the Royal Navy at a time when there were great advances.

Many new classes of warship were commissioned to be armed with missile and advanced gunnery systems. But in particular, he laid down the hull of Britain's first submarine based Polaris ballistic missile nuclear deterrent HMS Resolution in February 1964, to be launched by Queen Elizabeth, the Queen Mother in 1966. HMS Resolution was followed by Repulse in 1967, Renown in 1967 and Revenge in 1968. These ships served as Britain's nuclear deterrent for thirty years.

Further design and construction programmes during Sims period as Head of the Royal Corps of Naval Constructors included a large helicopter-carrying cruiser, a new design anti-submarine frigate, a guided missile destroyer and a new mine-countermeasure vessel. These vessels included extensive use of electronics, gas turbine propulsion and new weapon systems. It was almost certainly the most intensive period of change that the Royal Navy had known and Sims presided over all these programmes. He was a hard taskmaster but led by example. He was knighted in 1960.

Sir Alfred Sims served as Director General Ships, and Head of the Royal Corps of Naval Constructors, for ten years, retiring in 1968. Retirement did not see the end of Sir Alfred's activities. He was soon engaged in work for the Civil Service Commission and for various institutions concerned with maritime affairs and education. He was elected as the first professional President of the Royal Institution of Naval Architects in 1971 and served in this position for five years, after which he was elected an Honorary Fellow of the Institution, the highest honour that the Institution can award. He was Prime Warden of the Worshipful Company of Shipwrights 1975/76 and was in great demand as a speaker and as a lecturer. He was an Honorary Research Associate of the University College, London and was actively concerned with Bath University, being awarded the Honorary degree of Doctor of Science in 1974.

Sir Alfred James Sims, KCB, OBE, DSc, RCNC Warship Designer and Submarine Expert died at the Forbes Fraser Hospital, Bath on 25th, August 1977 in his seventieth year following a long and distinguished career associated with an incredible number of naval projects.

J C Calderwood

ROGER HOPKINS 1775–1847

Civil Engineer

Born in 1775, Roger Hopkins was one of the sons of Evan Hopkins of Llangyfelach who was engaged in the late eighteenth century in the construction of canals, tramroads and other works associated with the mining industry of South Wales. Evan was responsible for the design and construction of the inclined plane at Glynneath connecting the canal network and this plane, unusually, used a Trevithick high-pressure steam engine to transfer the canal barges from one level to the next. There followed a contract to build the Aberdare Canal in 1809 and with son David, a further tramroad on to the Aberdare Ironworks. His son Roger had by this time emerged as an engineer in his own right having received training and experience from his fathers activities.

Roger Hopkins married Mary Harris, daughter of the Reverend R Harris of Pwllheli, Caernarvonshire, at St Mary's Church, Swansea in 1806. In that year he became trustee of the Baptist Meeting House of the Swansea General Baptist Church. He was elected a corresponding member of the Institution of Civil Engineers in 1824.

Hopkins had, in 1804 been involved with the tramroad between Pen-y-darren and Abercynon in South Wales upon which Richard Trevithick tried the first railway locomotive steam engine. In 1810 he was engaged as engineer on the Monmouth Railway which was built partly through the Forest of Dean. In 1811 he was permitted to supervise work on the Severn and Wye Railway, where progress was poor and three years later came to Bideford to plan a tramroad or railway for Lord Rolle, to run alongside the River Torridge to Great Torrington. This project came to nothing.

In April 1821 the Plymouth and Dartmoor Railway appointed Hopkins as assistant engineer requesting he inspect and report on the state of the railroad between Crabtree and Jump (Roborough), where it seemed that William Stuart, the part-time engineer in charge, had deviated from the agreed route. The findings from Hopkins's report were so serious that it became necessary to amend the earlier Act of Parliament approving the works. Hopkins was sent to Parliament to guide a new Bill at the Lord's Select Committee stage and, with the Earl of Shaftesbury in the Chair, stated to the committee 'that the necessity for the present application to parliament for the Bill was not manifest until the month of April last, and originated in the impracticability the Railway found with proceeding with the work on the original line . . .' A new Act was passed, and William Stuart was dismissed. Hopkins completed the supervision of the construction and the railway was opened in 1823.

During this same year Hopkins competed against James Rendel for the approval of the Earl of Morley to be allowed to construct a bridge at Laira, Plymouth. Hopkins wished to construct a multiple span wooden bridge and Rendel, planned first a suspension bridge and then a five span cast iron bridge. In the event Rendel was successful in this project but at the same time Hopkins was successful in a scheme for building a wooden bridge between Shaldon and Teignmouth.

Late in December 1823 Hopkins set off for an extended spell in London where for the next five months he assisted in the preparation of an estimate and tender to supply Dartmoor granite for the whole construction of the new London Bridge. The Plymouth and Dartmoor Railway Company would benefit from this by transporting granite from Dartmoor to the quays in the River Plym estuary. Still in London, he finalised the design in February 1824 for the proposed bridge between Shaldon and Teignmouth.

The Bill to erect the bridge at Teignmouth received Royal assent in June 1824 and three years later the Teignmouth and Shaldon bridge was opened to traffic by the Duchess of Clarence. It cost £20,000 and measured 510 metres in length, comprised thirty-three timber arches and masonry approaches with a swing section over the main channel. It was the longest wooden bridge in England and only surpassed in the whole of Europe by the Pont de Lyons.

In 1827 the Hopkins family were established in Plymouth at 5 Brunswick Terrace, where Roger lived with his wife, Mary, and three sons Rice, Thomas and Evan. The eldest son, Rice who was born at Swansea in 1807, began his career on the tramroad, at the age of fifteen, as a pupil of his father and was elected a corresponding engineer of the Institution of Civil Engineers in 1836. It is interesting to note that Evan, the only son not to become a civil engineer, married the daughter of William Stuart, whom Hopkins had displaced from the Plymouth and Dartmoor Railway.

In 1828 Roger Hopkins designed and constructed the Royal Union Baths which were opened in May 1830 to much praise. However, within twelve years they were demolished to make way for the Millbay railway.

In 1831 he returned to North Devon to make a survey for the proposed Bideford and Okehampton Railway but this 34 kilometre route did not come to fruition. Also in 1831 he developed a acheme for the formation of a floating harbour at Swansea, together with a bridge across the river and the proposed new channel.

In 1831, Sir William Molesworth, a landowner, engaged Hopkins to survey a railway route from Wadebridge to Wenfordbridge with branches to Bodmin and Rutherbridge. The Bodmin and Wadebridge line was Cornwall's first standard gauge railway and also the first with steam traction. It was opened from Wadebridge to Bodmin and Wenfordbridge three years later.

In 1836 the partnership of Roger, Rice and Thomas Hopkins, based at Bath, owned mines in South Wales and built, owned and directed the Victoria Ironworks in Ebbw Vale. In March of that year they proposed a railway from Tremoutha Haven to

Launceston and in 1837 they built a 11 kilometre tramroad from their pit at Gwauncaegurwen in the Swansea valley to the Swansea canal. However by 1840 the Victoria Ironworks had failed and the works were handed over to the Monmouthshire and Glamorganshire Bank Company in repayment of a debt of £12,500.

By late 1842, Roger Hopkins had turned his back on South Wales and settled in Boulonge, France. In March 1845 he wrote to David Mushet at Colford, Gloucestershire, who had previously recommended Hopkins to the Plymouth and Dartmoor Railway, asking him to join in a new company to erect furnaces, not only in Boulogne, but also all over France. Hopkins does not appear to have received Mushet's support.

He returned to England and died at the home of his elder son, Rice, at 109 Upper Stamford Street, Lambeth, on 27 June 1847 in his seventy-second year leaving a legacy of remarkable civil and railway engineering works.

A B George

JOHN AMBROSE FLEMING 1849–1945

Electrical Engineer

There can be no doubt that John Ambrose Fleming deserves to be listed among the ‘giants’ of electrical and electronic engineering research and applications during the second half of the nineteenth century and the first half of the twentieth.

He was born in Lancashire in 1849, the eldest of seven children of James Fleming a Congregational Minister and his wife, Mary Ann. The family moved to London in 1853, to be near to his maternal grandfather, John Bazley White, who lived at Swanscombe in Kent where, at a very early age, Fleming saw and used mechanical tools in his grandfather’s Portland cement works in Kent.

At University College School from 1863, he quickly demonstrated a great ability in mathematics and soon developed ambitions for a career in engineering. Unfortunately, he was unable to afford the fees for this training so decided to pursue a career in teaching science. He enrolled at University College, London (UCL) in 1867 to study experimental physics, chemistry and mathematics. Physics, chemistry and maths, formed the launch pad for engineering careers, both then and now.

Fleming suffered the experiences of all impoverished students which are by no means modern phenomena and during 1868 financial difficulties forced him to temporarily discontinue his education. However, a post in a City stockbroker’s office enabled him to study part-time for the University of London BSc, in which he received a first class honours in 1870. After graduating, he took a post teaching science at Rossall School in Lancashire and when, by 1872, enough money had been saved, he returned to his chemical studies at the Science Schools in South Kensington.

Fleming's growing passion though was electrical engineering which drew him to the physics laboratory and the experiments being conducted there. He was invited to give the first paper at the inaugural meeting of the Physical Society of London in 1874 and following this recognition, he was appointed science master at Cheltenham College. He had, by now, become in modern terms 'a workaholic'.

He read the works of Michael Faraday on electro-magnetic induction and developed ambitions to become involved with proposals for national standards of electrical resistance, corresponding with James Clerk Maxwell at the new Cavendish Laboratory in Cambridge. He was anxious to study under Maxwell at Cambridge and joining St. John's College there he began to study for the Natural Sciences Tripos for which he gained a first class honours in 1880 finding time also to pass the London University DSc examination in the summer of 1879. This same year saw the death of his father so, never one to shirk responsibilities, in addition to his lecturing duties he worked in the university's engineering workshop in order to support his widowed mother and younger brothers and sisters.

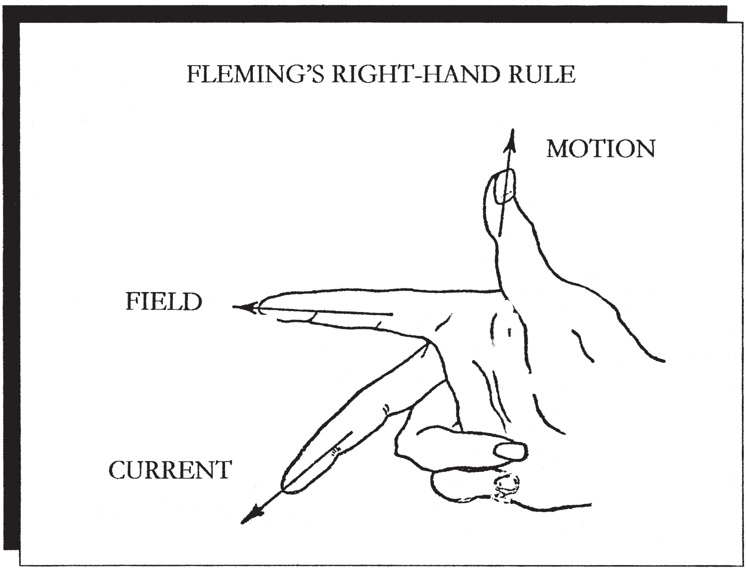
He was married to Clara Ripley on 11 June, 1887.

Fleming was appointed Professor of Physics and Mathematics at University College, Nottingham in 1881, resigning this post one year later in favour of a well-paid consultancy with the Edison Telephone Company in London. This company later merged with the Swan lighting company to form Ediswan and the first Ediswan filament bulbs were manufactured at their Ponders End factory

As the Company's 'chief electrician' he developed innovative photometric apparatus for the factory's quality control process, then in 1884 received another invitation – to lecture electrical technology at University College, London. At UCL, Fleming built his own laboratory but maintained very strong links with the Ediswan Company. In the following year he was appointed as the first Professor of Electrical Engineering at UCL, a post he held until his retirement in 1926.

To give his students clear guidance in predicting the motion of a current-carrying body (conductor) in a magnetic field, Fleming devised, about 1885, his famous 'Right-Hand Rule'. viz. 'If the first finger of the right hand is pointed in the direction of the magnetic flux (field) and the thumb is pointed in the direction of the conductor's motion, then the middle finger, held at right angles to both the thumb and the first finger, indicates the direction of the induced force'. Untold numbers of students of physics and electrical engineering, over the last one and a quarter centuries are eternally grateful to Ambrose Fleming. They have been able to reproduce this diagram and so earn a valuable few examination marks. Of course, for many years a number of the more ill-mannered students, caught by their lecturers sticking up two fingers, have been able to protest their innocence by claiming that their thumb was included !

In 1885, Fleming became profoundly interested in the use of alternating currents for long distance power transmission and his



researches culminated in his books ‘The Alternating Current Transformer’ – 2 volumes 1889–92.

Around this time, another ‘giant’ in the early years of electrical research and development was Ferranti who designed transformers of various sizes and proposed electrical power should be generated on a large scale, outside the great centres, where land was cheap and both water and coal were readily available. The installation of the first large-scale power station at Deptford Works was successfully completed in 1888 but there were dangerous surges in the famous 10,000 volts Ferranti electricity mains cables laid from the Deptford Power Station. Fleming was consulted and was able to suggest remedies.

It is however, even considering all Fleming’s other achievements, the invention and research related to the Thermionic Valve which ensures his place among the greats in the history of electrical and electronic engineering. His key discovery, made in 1904, was a revolutionary new technique for handling high-frquency electro-magnetic waves, thus making radio transmission possible and marking the birth of modern electronics.

Fleming realised that use could be made of an effect noted by Edison in that, if a metal plate is introduced into an ordinary evacuated carbon filament electric lamp then current will flow in one direction only. From this fact he developed a device which would act in relation to electric current in the same way that a flap valve acts in a water-pipe. The system was improved later by others, but Fleming had made the fundamental break-through.

The background to this invention can be traced back to Edison who had encountered a major problem with the carbon filament lamp – the blackening of the inner glass of the bulb caused by the evaporation of the carbon. The lamp had a filament formed into a single loop and it was noticed that a thin line was formed on the glass wall where the carbon deposit was lighter.

Fleming was aware of the Edison Effect and his first published comment on this was in the January 1890 Proceedings of the Royal Society of London from which it was clear that Fleming had been carrying out his own research. The basic physics may seem quite elementary today:

when a piece of metal is placed in a vacuum and heated, some of the electrons break away and form a cloud near the surface. This breaking-away or boiling-out of electrons from a metal is called thermionic emission.

Edison had noticed this effect but it was Fleming who showed that the electrons sent out from the heated filament could be attracted to a positively charged adjacent plate called an anode. So the diode valve, a vacuum tube containing a heated emitter and a plate, capable of changing (rectifying) alternating current to direct current was born.

Although the basic work on the diode valve had been completed by the mid 1890's there were no radio applications at that time and a few years were to elapse before he was able to claim his prize by being granted a patent for his Thermionic Valve on 16 November 1904.

On 9 February 1905, Fleming's new device the Thermionic Valve was revealed to the world in his paper read at the Royal Society 'On the conversion of electrical oscillations into continuous currents by means of a vacuum valve'. Marconi was persuaded to adopt the thermionic valve but by including an additional circuit, it was Marconi not Fleming, who converted the valve into a robust detector of wireless signals. By 1906, valves began to be used as wave detectors in practical wireless telegraphy and an amendment to Fleming's two electrode valve was made by an American patentee who produced the three electrode valve which could act as an amplifier as well as a detector. Developments in wireless telephony were to lead to extremely important scientific contributions for the Allied Forces during the First World War.

Towards the end of the nineteenth century Fleming had turned his attention to the subject of alternating currents at higher frequencies in Wireless Technology and he became Scientific Adviser to the Marconi Wireless Telegraph Company. He was responsible for the design of most of the electrical equipment at the Poldhu, Cornwall, station used by Marconi in 1901 when the transatlantic communications from Nova Scotia were achieved. In fact the plans for the first long distance wireless station in the world at Poldhu, Cornwall, were drawn up in the Electrical Engineering Department at UCL.

Marconi failed to adequately acknowledge Fleming's contribution to the transatlantic transmission and relations between the two became very strained. Marconi discontinued Fleming's advisory role to his company in 1903 but a few years later the consultancy contract was renewed. It required Fleming to surrender all patent rights to the Marconi company so he did not receive the financial rewards expected for this research.

However, he played an important role in the Marconi company's many years of bitter litigation with the American, de Forrest, over the originality of de Forrest's 1906 patent for the three electrode valve, which was subsequently employed as an amplifier in many radio receivers. Fleming's apparent victory in the American courts in 1917 was overshadowed by the death of his wife. Ironically, it was only two years before his own death in 1945 that the American court overturned the original verdict, by ruling that Fleming's patent had always been invalid.

Fleming continued with his major research programmes, produced technical publications and lectured on the new electrical technologies in the Christmas seasons at the Royal Institution in 1917–18 and 1921–22.

In 1926 he retired from University College London, almost 77 years of age, and lived in a house in Sidmouth, Devon, built to his own design, with his two sisters. He used the basement as a laboratory and this area was a private domain. Maintaining contact with UCL after his retirement he was, as professor emeritus, in demand to give special lectures which involved frequent journeys to London. Later he had an additional motive for his visits to London, other than his academic reasons. He had met a popular young singer, Olive Franks from Bristol who often gave concert performances including work for the BBC in London. Fleming attended many of these engagements and they were married in 1933.

Having been elected as vice-president of the Institution of Electrical Engineers in 1903 he received the Faraday Medal of that Institution in 1929 and was also knighted that same year. He was also elected president of the Television Society of London.

Small, localised electric power stations had been springing up all over the country including Exeter and Fleming acted as advisor to several of these.

In his few periods of relaxation Fleming enjoyed painting, sketching and foreign travel. Unfortunately, he had experienced hearing difficulties from birth and his deafness worsened as he became older. Not an easy man to get on with, this hearing problem was possibly a contributing factor. He eventually became chronically deaf and more difficult and unreasonable, often raging at shop assistants in his local newsagents if the newspapers had failed to arrive, even during the war years.

During the latter part of his life Fleming was a man of strong religious convictions and both he and his wife were regular worshippers at Sidmouth Parish Church. He died at his home in 1945 ninety five years of age and was buried at Salcombe Regis.

As part of the UCL Introductory speech given at the 1927 Centenary Address, the Chairman said: '. . . for nearly, if not quite, half the century . . . Professor Fleming has been contributing to those changes in the political, social and business life which are due to mechanical invention, which is the fashion to call progress, and more especially he has contributed to the necessary machinery for communication by telegraph and telephone both with and without wires'.

It is impossible that he, or in fact anyone, could have foreseen the world-wide explosion in the use and sale of mobile phones in recent times or even anticipated the dramatic increase in size and weight of large power transformers. But these dramatic developments have occurred and it is largely due to the pioneering research and subsequent practical applications inspired by Fleming that today we can take these and many other electronic and electrical devices for granted. Sir (John) Ambrose Fleming must always, quite justifiably, be remembered as 'The Telecommunications to Transformers Man'.

J J Brough

HENRY YOUNG DARRACOTT SCOTT 1822–1883

Military Engineer and Chemist

Henry Scott's versatility had much in common with other engineers of the Victorian Age. He retired an honorary major general, having served as a military engineer frequently concerned with fortifications, but studied sufficient chemistry to be able to develop and patent several fast-setting cements. Like many soldiers of that period he was seconded for civilian service, during which time he co-ordinated the design and construction of the Royal Albert Hall in Kensington, the work for which he is now probably best remembered.

Henry Young Darracott was born to Edward and Elizabeth Scott as their third son in January 1822 in the Britton Side, now called Bretonside, area of Plymouth near Sutton Pool, and was baptised in the nearby church of Charles the Martyr. His father had quarrying and brewing interests but was financially sufficiently comfortable to regard himself as one of the gentry. The young Scott was educated privately and entered the Royal Military Academy, Woolwich, the forerunner of Sandhurst, as a cadet in 1838. He was commissioned as a second lieutenant in 1840, pursued further studies at the Royal Engineers Establishment in Chatham and held brief appointments at Woolwich and in Plymouth.

In 1844 he was promoted first lieutenant and posted to Gibraltar where he was engaged on the reconstruction of the fortress. The engineering and supervisory skills he then practiced, although directed to a military objective, were similar in kind to those of the great canal, bridge and tunnel builders whose work became known as 'civil engineering'.

It was in Gibraltar, as the fortifications were being dug, that Scott first observed the interaction of freshly exposed shale with the atmosphere and became interested in its potential as a raw material for cement making. This observation was to have a major impact on his subsequent career, converting him from a competent military engineer into an innovator in building technology and an entrepreneur.

In 1848 Scott was posted to Royal Military Academy Woolwich as Assistant Instructor in field-works, fortifications. He also commenced a chemistry course at Kings College London and began his experiments on a shale-based cement. Scott was made Senior Instructor during 1851, and in November of that year was promoted second captain, becoming a captain in 1855.

It was in this year also that he married Ellen Selena Bowes, the youngest daughter of a major general. They had a large family, the adequate support of which may have been an extra spur to his natural talent for invention. Until 1872, when pay scales were revised, an army officer could scarcely survive on his army pay, and most depended on 'private means' or family money for financial stability. Scott undoubtedly channeled his technological expertise into money-making activities, as he was entitled to do, in parallel with his military duties.

During 1854 and 1855, whilst at Woolwich, Scott invented and patented a novel cement with fast setting properties that made it particularly suitable for plaster and other decorative work. This was a direct result of his laboratory experiments with sulphuric acid and quicklime (don't even think of copying him!) in which he sought to reproduce the natural reaction in volcanic regions of sulphur oxides and moisture on calcium-containing minerals. By the 1870's Scott's Patent Cement was better known as 'selenitic cement', a reference to the mineral selenite or gypsum. Review articles about cements in the 1870's and 1880's frequently made reference to his patents.

Scott's work needs to be seen in the context of cement technology of the time. Using the word 'cement' for any paste or mechanically plastic material with good adhesion to a solid substrate and capable of subsequent hardening, three broad compositions were known – lime mortar, Portland cement and Plaster of Paris.

Lime mortar had been known since early medieval times. Here limestone was burnt to produce quicklime, the lumps of which were then slaked with water producing a fine powder. More water was added to this slaked lime which was beaten into a thick slurry before incorporating the sand it was intended to bind. The resulting mortar was versatile, but took a long time to set firm, and even then its final hardness and strength were low and its water resistance poor. If the original limestone contained a natural admixture of clay, it was observed that the mortar's properties improved, but the lumps were less likely to form a powder on slaking.

A further development had been Portland cement, patented in 1824. It was first produced in quantity in 1845 by calcining a slurry of chalk and clay in upright kilns as a batch process. Continuous process rotary kilns were not used until 1880. This cement had much improved properties especially of strength, water resistance and reduced time for hardening. However, the extensive ball-milling necessary to make it fine enough for good adhesion raised its price significantly. Additions of gypsum, ball-milled along with the fired cement clinker could be used to control the hardening time of the final product. Alternatively when gypsum is heated to 128 degrees Celcius it loses most of its water of crystallization, becoming Plaster of Paris once the calcined product has been finely ground. This was the material that Scott introduced, at 10 – 15% by mass, into a lightly clay-bearing quicklime before slaking. The resulting cement, when beaten into the conventional slurry and mixed with sand, set quickly, had very good adhesion and was particularly hard. Furthermore it could take up more sand than the common lime mortar, reducing the cost of its use, even after pricing in Scott's patent royalties.

These patents, recognizing the novelty of his contribution, covered the composition of the new cement, the process of making its precursors, compounding the raw cement and the method of producing the plastic mixture ready for application. The second patent proved to be commercially viable and a Kent cement maker began production. The new product was widely used in public construction projects, latterly for many of the London School Board's schools and the Albert Hall.

In 1855 Scott, by then a captain and still at Chatham, took charge of the chemistry laboratory and the surveying course there. He continued to experiment with his selenitic cement and laid the groundwork for the Royal Engineers' improved understanding of cement and concrete in military applications.

During his lifetime he was granted some fifty-nine patents relating to lime, cement and new kilns of which he was the inventor. Not all his patents were exploited successfully; a patent dated 1868 covered a process for treating raw sewage and producing a cement from the sludge, but the company set up for this purpose failed. By contrast, his Patent Selenitic Cement company was formed in 1871 and traded until the expiry of the patent after his death.

1856 saw the end of the poorly handled Crimean War against Russia. The inevitable public outcry at the conduct of the war led to criticisms in Parliament that had to be answered. In this Scott assisted the Royal Engineer Establishment's director in reforming the surveying and architectural courses offered there. He also pioneered a fresh approach to landscape field sketching, which was a necessary military skill in the days when a whole battlefield might be seen from a single vantage point and before the days of quick and convenient photography. His system was adopted at Woolwich and at Chatham, becoming a feature of the training of army officers generally.

In May 1863 Scott was promoted brevet-major, giving him the authority and privileges of the rank without the extra pay, and in early December to lieutenant colonel. He was then seconded to the civil service to work with the 'Commissioners of the Exhibition of 1851', the body which was responsible for carrying forward the ideals of science, technology and commerce that had been engendered by the Great Exhibition, and later to the Council on Education, Kensington Museum. He served as Secretary from 1873 until 1882.

This pattern of 'secondment to the civils' was common in the army of this period. Preparing for war, the army frequently had more trained manpower available in peacetime than could conscientiously be employed. Furthermore, despite many weaknesses, army training produced officers who also had the technical, managerial and administrative skills plus an ability to think on their feet, so much in demand for the numerous public works that accompanied the country's industrialization at this time.

On the death in 1866 of a fellow Royal Engineer officer who was serving as the architect to the Department of Science and Art, Scott was made his successor as Director of Works. A year later he began work on the Albert Hall as the co-ordinating manager underpinning its design and construction. Although his architectural knowledge was only basic, his skill was to draw together the disparate contributions of design draughtsmen, architects, decorative artists, engineers, manufacturers and suppliers. Here his social skills and ready ability to give 'credit where credit was due' served him and the project he was supervising, very well.

The Albert Hall's characteristic roof profile derived from a state-of-the-art elliptical beam design, enabling the oval ground plan of the hall to be spanned without the arena and seating galleries being obstructed by roof supports. In this, Scott was co-ordinating the efforts of leading structural designers, engineering companies and consulting engineers, one of whom was John Fowler, later to collaborate in the design and construction of the Forth railway bridge.

The roof was completed in 1871. Despite the assembly of such expertise, wide span roof design was still an inexact procedure. The story is told that Scott removed the final scaffolding support himself in an empty building, in case there was any substance in the gloomy predictions of some commentators that the structure would fall in, a story that echoes the experience of Brunel thirty years earlier. Brunel then had teased the detractors of his brick railway bridge at Maidenhead by having the timber formwork supporting the elliptical arch secretly drawn back a few inches, but otherwise leaving it in place so that they assumed he doubted his calculations. The formwork blew down in a storm about a year later but, 165 years on, the bridge continues to carry West Country rail traffic, just as the Albert Hall's roof remains in place.

Scott was promoted brevet-colonel in 1871 and retired from the army having been made an honorary major general and civil companion of the Order of the Bath, CB. He became an associate of the Institution of Civil Engineers, later publishing with Gilbert Redgrave, a designer draughtsman from Albert Hall days, a paper on the manufacture and testing of Portland cement. Scott became a Fellow of the Royal Society in 1875.

General Scott's last months were sad. A government decision early in 1882 transferred responsibility for other public buildings in the South Kensington complex away from Scott, and he was dismissed from the Secretaryship of the Board without financial compensation. With his wife and eight of his fifteen children still dependent on him, the stress brought on by his abrupt dismissal seriously damaged his health and he died aged 61 years in April 1883. He was buried in Highgate Cemetery, London.

During his life he had influenced the practice of military engineering, shown himself to be a serious inventor and entrepreneur, and was a leading contributor to construction and development in the area of South Kensington, London.

R D Battey

GEORGE JACKSON CHURCHWARD
1857–1933

Engineer and Inventor

George Churchward's father owned and farmed land in the South Devon countryside. George as a youth was of sturdy build with ruddy complexion, fond of the outdoors, especially when fishing and shooting, and would have been expected to follow his father's footsteps in making a living from the land. However, his career was to follow a quite different path.

George was born in 1857 at Rowe's Farm, Stoke Gabriel, the second son of George Churchward and his wife Adelina, who raised two other sons and two daughters there. The Churchwards were a prominent family in and around Stoke Gabriel, to this day a delightful village close to the River Dart. George's uncle, Frederick Churchward, was the last squire of that community, and was sufficiently affluent to be able to support the education of the next generation of Churchwards.

When George was old enough, he attended Totnes Grammar School, some five miles from his home, during which time his uncle arranged private tuition for him during school holidays, together with his own son Charles and another nephew, Paul. Whilst at the Grammar School, it was recognised that George had an unusual ability with mathematics and an enthusiastic interest in all kinds of machinery. As his scholastic talents were developing, it seems likely that his mechanical interest was fostered by regular sights of locomotives travelling the South Devon Railway, which had served Plymouth and Exeter via Totnes since its inauguration in 1849.

In 1873, at the age of 16, George became articled to John Wright, the Locomotive, Carriage and Wagon Superintendent of the South Devon Railway, whose locomotive works were situated at nearby Newton Abbot. In 1875, he and fellow apprentice Richard Granville showed their mechanical ingenuity by designing and building one of the earliest motor cars. It was a three-wheeler with a large single wheel at the front, steered by a tiller, and driven by a steam engine they had designed. As recently as 2000, it took part in the annual London to Brighton run, when it was the oldest vehicle in the outing.

In 1876, the Great Western Railway, which had become the largest railway system in the country, took over the South Devon Railway. This gave Churchward the opportunity of improving his prospects by going to Swindon to complete his four-year pupillage under James Armstrong, the Locomotive Superintendent of the Great Western, where he gained invaluable experience in all aspects of railway development and management.

On completion of his training, Churchward spent three years on various drawing office tasks before being assigned in 1880 to work with his boss's son, Joe Armstrong, in the design of a new form of braking system. The power and speed of locomotives had increased dramatically and there was concern that the capacity of braking systems had not kept pace. Within two years, the first vacuum brake system was in production and this proved to be a huge success. Churchward's creative flair was duly recognised and his career advancement was undoubtedly boosted. In 1882, at the age of 25, he spent a brief period as an inspector of materials before being appointed Manager of the Carriage Works at Swindon in 1885.

During the following years Churchward was heavily involved in the development of carriage and wagon improvements to meet the constantly growing demands for transportation by rail. One vitally important task was to devise ways and means of coping with the difference in track width adopted by rival railway companies. Brunel had built the Great Western system to a gauge of 7 feet (2.1 metres), believing this would be safer at the higher train speeds he envisaged, but most companies had invested in George Stephenson's gauge of 4 feet 8.5 inches (1.4 metres). This difference created expensive delays for Great Western at change-over locations. After much deliberation, Great Western eventually had little alternative but to adopt the narrow gauge, but until this was achieved in 1892 it had to operate with rolling stock capable of running on both gauges. Churchward devised a means of converting carriages to suit both gauges for which the change-over took no more than 30 minutes. It was done by supporting the carriage frame on trestles whilst both four-wheeled bogies were withdrawn by hydraulic means and replaced by similar bogies of the alternative gauge. This was one of many of his pioneering achievements, which included the introduction in 1892 of Britain's first corridor train, duly equipped with the luxury of steam-heating throughout.

By 1895 Churchward had clearly demonstrated his exceptional ability and was made Assistant Manager of the locomotive works at Swindon. He greatly relished this move as he had developed a huge passion for steam locomotives during his pupillage. From 1899, due to the failing health of William Dean, the Locomotive, Carriage and Wagon Superintendent, Churchward was effectively in charge of these departments before officially succeeding Dean in 1902, at the age of forty-five. He then became the driving force behind the expansion and modernisation of the Swindon works, which by the time of his retirement in 1921 had held the accolade of being Britain's most modern locomotive works for at least a decade. This was in spite of the first World War, which had a great impact on the Swindon works, when it became heavily involved in the manufacture of munitions. Churchward also directed this diversionary operation, which was recognised by his appointment to CBE in 1918. At the same time, he was an active member of the Institution of Mechanical Engineers and the Institution of Civil Engineers, and in 1917 was elected President of the Association of Railway Locomotive Engineers.

The enhancement of the Swindon works was a direct consequence of Churchward's outstanding ability as a designer and builder of locomotives. The maximisation of engine power allied to economy of running was of paramount importance during a period when there was competition, not only between British railway companies, but from abroad also, especially France and USA. Churchward had the knack of spotting weaknesses and opportunities for improving performance in all aspects of his machines. His technical genius, meticulous approach to research and design, and constant pursuit of engineering excellence ensured the pre-eminence of his locomotives.

The output of locomotives, carriages and wagons from the Swindon works during Churchward's reign was truly phenomenal. More than 3,000 locomotives were manufactured under his direction, together with the rolling stock they were built to haul. Many notable feats were performed by his engines. In 1904 the famous 'City of Truro' was the first to haul a train at a speed of 100 miles per hour. The GWR heavy-freight engines, known as the 2800 class, were outstanding. In 1906 No. 2808 set the haul-breaking record with a train in excess of 2,000 tons, and when No. 2807 was withdrawn from service in 1963, it had clocked 1,472,687 miles during a working lifetime of 57 years. It is quite remarkable that Churchward's locomotive designs, subject only to minor modifications, endured for 25 years after his retirement.

A significant feature of GWR was Churchward's introduction, between 1903 and 1911, of a series of nine different locomotive types of advanced design, to meet the whole range of the company's needs, from main-line passenger express to shunting in the local goods yards. He also introduced a high level of standardisation of components for use throughout his range of locomotives, which simplified production and maintenance during this period of robust expansion of rail transportation.

It was customary in those days for the leaders of industry and commerce to become involved in local government affairs. Accordingly, Churchward joined the Swindon New Town Local Board and was later elected a member of the Swindon Urban District Council when it was established in 1894, becoming the chairman 3 years later. In 1900, Swindon was granted a Charter of

Incorporation by Queen Victoria, and Churchward became the first mayor of the new Municipal Borough. He maintained his interest in the town's affairs for many years, and became the first honorary freeman of the borough in 1921 in recognition of his extensive services to the community.

Throughout his adult life, Churchward displayed many invaluable leadership qualities. Undoubtedly, he had great depth of vision and applied his mind to problems in a logical, calculating manner. He maintained a respectful relationship with technical staff and factory workers alike. He spoke to them in a language they easily understood, and inspired them by his enthusiasm to contribute their best efforts, for the betterment of their industry and their community. In an era when bowler hats were a mark of authority, and those wearing them were to be feared, he regularly wore a trilby hat, which displayed his approachability. En route from his home 'Newburn', on the fringe of the works complex, to his office desk he would talk with foremen and chargehands, to gain their views on the jobs in hand. There are reports of his picturesque language, and his delight in mild practical jokes, but despite this familiarity, he did not tolerate unpunctuality, and expected high standards from those in his employ. No doubt these admirable characteristics played a big part in the making of the hugely successful locomotive industry of Swindon.

The circumstances of Churchward's retirement at the end of 1921 are interesting. He was in charge of Great Western engineering for over twenty years, his post being re-designated Chief Mechanical Engineer in 1916, but the impetus he imparted to the company seemed to founder a little following the first World War. A considerable proportion of the nation's workforce experienced the fighting at first hand in which the bloody trauma of trench warfare dominated. No doubt the attitudes of survivors to the conditions of their later employment were affected. Not surprisingly, the post-war government made large concessions to the trade unions, but Churchward was not always prepared to accept trade union demands in his works. His despair reached the point in 1921 when he declared 'I can see that it is time 'The Old Man' retired', and so he did, at the age of sixty-four. It seems there was no ill-feeling, as the workforce contributed over £500 to a retirement gift, which was a substantial amount in 1921. Churchward put this sum into a trust fund, the interest from which was destined to fund book prizes for successful students.

After retirement, Churchward continued to live at 'Newburn'. He had never married, and little is recorded about his private life. However, it appears that he had retained his Devon-inspired love of the countryside and his favourite pursuits of fishing and shooting throughout his working life. And he maintained a happy relationship with his two sisters, Mary and Adelina, who were still active in the Stoke Gabriel community. However, it seems that he was unable to totally divorce himself from railway matters, and one wintry day in December 1933, he set out on one of his favourite walks from 'Newburn', part of which took him along the adjacent main line track. The weather was miserable, and his gardener suggested it was unwise to do the walk in the prevailing low-lying fog. But Churchward insisted that he wanted to inspect a section of the track, the condition of which concerned him. So he went ahead, but tragically did not complete the walk. Hampered by poor visibility and the deafness of advancing years, he was struck and killed by an engine derived from one of his own designs.

Churchward was buried at Christ Church, Swindon, but he is not forgotten in Stoke Gabriel. The headstone at the grave of his two sisters in the churchyard of St. Mary and St. Gabriel includes a simple commemoration to George Jackson Churchward CBE. Nearby at Rowe's Farm (Grid Reference 847578), there is a small tablet on the wall of the building to commemorate the 140th anniversary of his birth, unveiled by the Chairman of the Railway Division of the Institution of Mechanical Engineers in 1997. Modest reminders of a son of rural Devon, whose fame in the fast-moving world of engineering had spread nationwide and beyond.

J P Westwell

THOMAS MUDGE 1715–1794

Clock and Watch Maker

The measurement of time is a problem that has exercised man's mind since the early days of civilisation and as the years went by the need for a reliable timekeeping instrument increased. The first method for measuring time was probably the sundial but this only functions in daylight hours and when the sun is shining. Various other systems were tried with limited success but the advent of the industrial age gave rise to the birth of a body of watch and clock makers whose unique skills enabled them to create very reliable timepieces.

One such person was Thomas Mudge who invented the lever escape mechanism. Mudge was one of the most brilliant watchmakers the world has known and it was this invention that allowed the movement of timepieces to be controlled and regulated so that they kept very accurate time.

Mudge was born into a remarkably talented family in the city of Exeter and it is worth recalling a little of the history of his family, which distinguished itself in so many ways.

His father, the Reverend Zachariah Mudge was born of relatively humble parents in 1694 and studied at Exeter Grammar School until he was thirteen or fourteen years of age. His original wish was to become a member of the non-conformist church but instead he became a master at a local school run by a Dr John Reynolds and later at Bideford Grammar School. Zachariah's three eldest children, one of whom was Thomas, were born in Exeter. Thomas had three younger brothers, the first who was three years his junior, became the Reverend Richard Mudge, a composer who is said to have impressed even Handel himself when playing the harpsichord. Another brother, six years younger went on to become a physician and won a prestigious gold medal for his work on reflecting telescopes. Altogether there were six children of the marriage.

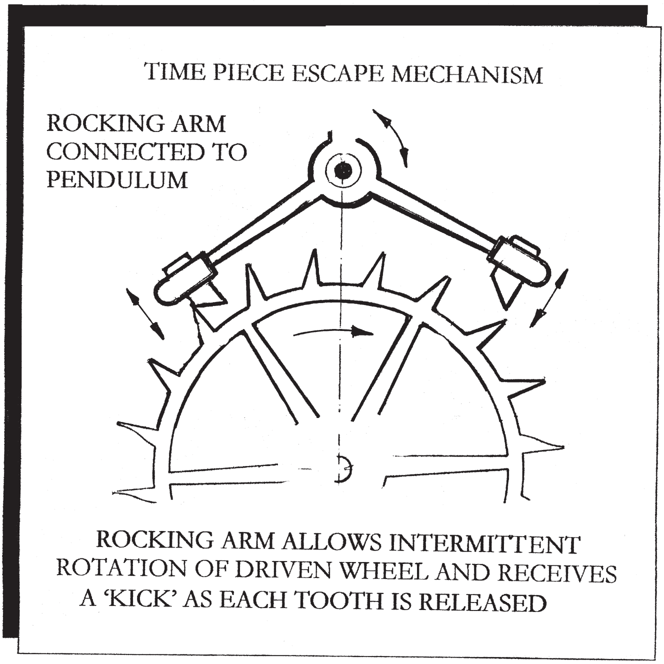
It was at about the age of fourteen years that the young Thomas, having shown an aptitude for things mechanical, (he would take clocks apart and reassemble them with ease) was apprenticed to George Graham of London, one of the most eminent watchmakers in the country. Records of the time indicate that the premium his father paid for this apprenticeship was £30 and the Worshipful Clockmakers Company register of apprentices shows that it was for a minimum of seven years from May 1730.

It was not unusual in those days for this premium to be handed to the business owner's wife to help pay for the apprentice's food and lodgings at the workplace. Mudge displayed great ability and enthusiasm and after completing a highly successful apprenticeship, he was made a freeman of the Worshipful Company of Clockmakers of London on the 15th January 1738. During his service an apprentice was subject to a legal contract that could only be ended early by mutual agreement, hence the terms 'to become a freeman' at the end of a successful apprenticeship. Mudge continued to work for Graham for a further thirteen years before eventually taking over separate business premises nearby at 151 Fleet St. Graham is recorded as having died in 1751, without doubt, a very great loss to the profession.

Until about the late 19th century clocks and watches were, in the main, made to order and were far beyond the means of the average person. To meet the requirements of the man in the street, clocks were provided on church towers and public buildings to ensure he attended church services and his place of work on time many chiming every quarter of an hour.

In about 1752 after becoming established in his own right, Mudge was approached by another highly acclaimed London watchmaker, John Ellicott, and asked to make an equation watch for King Ferdinand VI of Spain. An equation watch is one which corrects for the non-regularity of the earth's motion by adding or subtracting seconds from solar time inorder to obtain a 'mean time'. Ellicott had turned down the request but considered Mudge to be one of the few craftsmen able to carry out the work. Making such a watch would prove to be a most complicated operation, calling for a mechanism that would show the sun time as well as normal time. Clocks of this type, even now, are very rare.

However, on learning that Mudge had been tasked with the undertaking by Ellicott, the King approached Mudge directly and gave him the instructions. In due course Mudge constructed the watch showing both true and sun times, as well as striking the hours and the quarters. He even went on to mount the watch in the top of a walking cane. The King was highly pleased with the result and told Mudge that he was prepared to give more than the 480 guineas (£504) that Thomas had charged him. This was,



of course, a very considerable sum of money at the time, equivalent to many thousands of pounds today.

Mudges' fame was spreading and in 1755 he took William Dutton, another past apprentice of the late George Graham, into his business. This enabled Mudge to spend more of his time improving and enhancing clock and watch mechanisms. His finest achievement during this period, was without doubt, the development of the lever escapement which is still used to this day to control and regulate the movement of many watches.

The escapement, or escape movement mechanism, is that part of a watch or clock, which converts the 'raw' power of the driving force e.g. main spring, weight, or electric motor into regular uniform impulses. This was achieved by the use of a small bar, carrying a tongue at each end, which is rocked alternatively into the teeth of a wheel. He was also one of the first makers responsible for using jewels as pin movement bearings which are still used to this day.

For the next five years or so all clocks and watches made were signed with the name Thomas Mudge but later when William Dutton became a partner in the business, this was changed to Mudge & Dutton and remained that way, even after Thomas left the Fleet St. business.

His lever escapement mechanism was included in a watch he made in 1770 for Queen Charlotte, wife of King George III. At present this watch is believed to be in Windsor Castle and still capable of keeping good time. It is said that Queen Charlotte held Mudge in very high esteem and it was through her recommendation that Thomas' second son the Reverend John Mudge was given the living at Brampford Speke near Exeter.

At this time the Admiralty had become increasingly concerned about the shipping losses resulting from mariners being unable to fix their exact position when at sea. For navigation purposes a watch must be very accurate indeed for although latitude can be determined by taking sextant readings of the sun, establishing the longitude is a more difficult process. The government of the day set up a Board of Longitude that offered a monetary award to the person who could make an accurate timepiece that would meet the Board's very strict specification. The award was eventually given to John Harrison and the chronometers he made can presently be seen on display at the Royal Greenwich Observatory.

Naturally Mudge who was also a contender for the award at the time. was very disappointed at not succeeding and in 1771, at the age of fifty six years he decided to leave his London business, return to the West Country and set up a workshop in Plymouth to devote his semi-retirement attentions to the further development of marine chronometers. Plymouth was chosen for several reasons, firstly for its very obvious seafaring activities and secondly, because his brother Dr John Mudge lived in the city. His late father, the Reverend Zachariah still owned a house there in which, it is believed, Thomas lived.

In 1774 he completed his first marine timekeeper which was submitted for examination and after testing, the Board of Longitude awarded Thomas £500 to construct two more. All three were then tested on long voyages at sea and while they performed with great accuracy under most conditions, the Astronomer Royal at Greenwich Observatory decided that some of the temperature variations experienced at sea affected the watches and a further award could not be given.

Naturally Mudge was again disappointed and told the Board that the testing methods they had used were, in his view, inappropriate. The Astronomer Royal was forced to defend the decision and an official inquiry was subsequently held at which Mudge was represented by his first son Thomas junior who was a Lawyer at Lincoln's Inn. This eventually resulted in a committee of Parliament recognising the watchmaker's outstanding ability and workmanship and in 1793 awarded him a further £2,500.

Mudge died at the age of seventy nine and an entry in the obituary list of the 'Gentleman's Magazine' of 1794 reads '14 November, at an advanced age, at his son's house in Walworth, London, the ingenious Mr. Mudge, late watchmaker in Fleet St.' Records show that his funeral took place on 21 November at the church of St Dunstan in the West and that he was buried in its Fleet Street churchyard. A portrait of Thomas Mudge hangs in the portrait gallery of the Worshipful Company of Clockmakers in the Guildhall, London.

Clocks and watches are, of course, no longer the sole domain of the mechanical engineer. Electronics are employed to control time and accuracy and with some, incoming radio signals are received within the watch to check not only the time but also the time zone in which the timepiece is being used.

Today, most watches are driven by small batteries and being mass-produced are relatively cheap, consequently it is not easy to appreciate the problems that faced Mudge and his contemporaries in the 18th century. Machinery has replaced the manual skills they so painstakingly acquired but a study of the many books on horology reveal the magnitude of the task that faced these early pioneers. They also provide a fascinating record of the development of clocks and watches, the complex mechanisms of which we now take for granted. The role of the engineer in the design and layout of such complex pieces of equipment is still an essential one.

S J Heard and A G Banks

ISAAC WATTS 1797–1876

Naval Architect

The nineteenth century witnessed remarkable changes in the design of warships. These developed from the three-decker wooden walls of Nelson's fleet which were propelled by the wind, to become armoured steel battleships with propellers driven by steam engines and with heavy guns mounted in turrets. Watts was a very significant figure in these developments.

Watts was born in Plymouth and baptised on 31 July 1797. He was the only son of William and Elizabeth Watts, and had two younger sisters, Ester and Marie. He was apprenticed to a shipwright at the age of thirteen or fourteen and he must have been a bright pupil because he subsequently passed the competitive examination for the School of Naval Architecture at Portsmouth. This School had been set up in 1810 following widespread worries that British ships were inferior to those of some other nations, notably France, although there is some doubt whether these concerns were really justified. This initiative was probably the first time that a major employer had set up a formal education and training scheme aimed at producing candidates for senior posts, but it also provided a means for dispelling concerns regarding the low standard of education of dockyard officers.

The School was small, the original intention being to enter twelve students each year, but in most years the number was much fewer, and when the School closed in 1832 there had been a total of only thirty graduates. However, a number of these made distinguished careers including Watts who entered the School in

1814 at the age of seventeen. Here he embarked on a tough course lasting seven years including studies of mathematics, mechanics, hydrostatics, drawing, French and naval architecture. These theoretical studies occupied about half his working hours, the remainder being devoted to practical work in the workshops and in building ships. During the last year of the course some months were spent at sea with the Royal Navy. Students were paid sixty guineas (£63) per annum during their first year, rising in steps during their course to reach 140 guineas (£147) per annum, the latter sum being equivalent to about £10,000 now. Any student today would be very happy to receive a grant of this magnitude, and no doubt Watts felt quite wealthy at a time when the average wage of workers was very low.

On completion of the course at the age of twenty-four he was employed in Portsmouth Dockyard. There were a number of Royal Dockyards in the UK at that time, the most important of which were Portsmouth, Chatham and Devonport. Together they comprised a major industrial organisation employing many thousands of men. The key trade was that of shipwright of which Watts was one, but many other skills were employed including joiners, riggers, rope makers, sail makers, block-makers, founders, oar-makers, mast makers and many others.

Promotion for Watts was slow, the way up being blocked by old stagers who tended not to recognise younger talent. It was not until 1833 when he was thirty-six years old that he became a 'Foreman of the Yard', a middle management post much superior to a foreman in a commercial yard. He remained in this position for the next thirteen years, during which time he married and had five children, two sons and three daughters.

Promotion finally came to Watts in 1846 at the age of forty nine years when he was appointed as Master Shipwright at Sheerness where he was effectively general manager of one of the smaller Royal Dockyards. The following year brought further promotion when he was appointed to work in Somerset House in London as First Assistant to the Surveyor. He now became responsible for the design of all new ships for the Royal Navy.

This was an exciting time marking the beginning of the introduction of steam power with screw propellers to supplement sails for the propulsion of warships. The Admiralty had been spurred on by the success of propeller trials carried out in 1839 in Archimedes, a ship designed to demonstrate screw propulsion. However, although the benefits of screw propulsion were accepted, iron hulls which were being introduced for merchant ships, notably I. K. Brunel's SS Great Britain, were not in favour for warships because tests had shown that shot from a naval gun passed through iron plates and also led to lethal flying splinters.

For ten years following his appointment to the Surveyor's office, Watts thus found himself designing new wooden steam battleships, adapting sailing ships under construction to steam, and converting existing sailing wooden battleships to steam by installing boilers, steam engines, coal bunkers and propeller shafts. All the machinery was installed low down in the hulls where it would be well protected from shots fired from an enemy vessel and this also kept the centre of gravity of the ship low, increasing stability.

In 1851, three years after his appointment to Somerset House, Watts went to France to visit naval establishments and to observe developments in ship design. This must have given him an opportunity to practice the French language which he had studied at the School of Naval Architecture thirty seven years earlier, and it was in France that he was impressed by the progress being made in the design and building taking place on the battleship Napoleon. She was designed as a vessel which relied on steam power with sail as auxiliary, which was the opposite of British practice at the time. On Watts' return to London, much increased effort was put into the building of Britain's first real steam battleship, Agamemnon, which was built at Woolwich Dockyard and launched in 1852 only five months after the French ship. Agamemnon, which had a complement of 860 men, had a massive wooden structure on the stern which enabled the detachable propeller to be hoisted out of the water when the vessel was propelled by sail alone.

This was a time when Britain and France were closely allied and from 1854 until 1856 they fought the Crimean War together against Russia. The war led to a major expansion in warship building, and Watts was responsible for the design of a large fleet of gunboats for this purpose. Agamemnon was the flagship of the British Black Sea Fleet and led the shelling of the Sevastopol forts in 1854.

After the end of the war, British relations with France became strained when it was realised that the French were challenging the dominance of Britain as the world's major sea power. Britain then embarked on a programme of designing even larger steam powered wooden frigates culminating in the Oriando which had an overall length of 111 metres. However, wooden ships of this size showed structural weaknesses and had to be reinforced with iron. It was apparent that the all-wood construction of ships was reaching its limits.

In 1857 the French planned to halt all construction of wooden ships of the line and planned a new fleet which was intended to be iron hulled. However, French industry was not at the time capable of producing iron structures on such a large scale, so the first three ships were planned to have wooden hulls armoured with solid wrought iron plates. The first of these ships, Gloire, was launched in November 1859, but news of her building had reached the Admiralty in London the previous year, and had been received with some alarm. It was decided that something must be done. Many in the Admiralty favoured cladding wooden hulls with iron plates, but Watts argued successfully for iron hulls, having concluded that a ship which would be long enough to carry the specified armament would only be satisfactory with an iron hull.

The ship that emerged, Warrior, was an iron-hulled, ironclad frigate intended to overtake and destroy any warship then afloat. She was a 'broadside' design having the guns located along the port and starboard sides behind openable gun-ports, and in this respect she resembled the 'wooden walls' of Nelson's fleet, but she was armoured and had steam power as well as sails. The armour plating consisted of a belt of interlocking wrought iron plates on each side of the ship bolted on to the iron hull. Each plate was 10 centimetres thick, 4.6 metres long by 0.9 metre deep with tongued and grooved edges to engage with the adjacent plates, and each weighed 4 tonnes. This side armour was backed by 18 inches (45 centimetres) of teak to form an impregnable citadel. A full scale section of the ship was built and fired on by heavy guns to confirm the effectiveness of this protection. No ship can be said to be the sole work of one person, and Watts was supported by a team including a fellow Constructor, Joseph Large, and a Chief Engineer, Thomas Lloyd, both of whom were graduates of the School of Naval Architecture. It was nevertheless the drive and determination of Watts that led to the success of the project.

The contract to build the ship was placed with the Thames Iron Works at Blackwall, and she was launched in December 1860, only 19 months after construction had started, and only a year after the French ship Gloire. However, Warrior was bigger, faster, stronger and more formidable than the French ship and its superiority was recognised worldwide. A sister ship, Black Prince, was laid down at Govan the following year, and this underlined the British superiority.

However, new concepts were in the wind in the form of turret ships, and Watts was in the forefront of these developments which would soon make ships like Warrior obsolete. The idea was that heavy guns should be mounted on armoured turntables where they could achieve a better rate of fire than broadside mounted guns, and were better protected from enemy fire. Watts designed an iron-hulled armoured turret ship, Prince Albert, and the wooden hulled Royal Sovereign, which were the first major British warships without sails.

However, Watts was reaching the end of his career. A re-organisation in 1860 had given him the title of Chief Constructor with a salary of £900 per annum which was a very substantial income at the time, and he was honoured for his services with a CB. He retired in 1863 having seen the Royal Navy through two technical revolutions, screw propellers and armour.

Watts' best known achievement, Warrior, lived on, thanks to her rust-resistant iron hull. She had a short active career in which she visited British and European ports, but she never fired a shot in anger, and after only about ten years she fell into obscurity. She was refitted in 1871 and became part of the reserve fleet, but by this time the 12 inch (30 centimetres), 35 tonne gun was in service which could pierce 14 inches (36 centimetres) of iron at 1000 yards (914 metres), and this spelt the end of Warriors active life. After spending time in a number of non-seagoing roles she eventually became a mast-less hulk used as a jetty at Pembroke Dock Oil Fuel Depot. There she remained until 1979 when she was rescued by a Trust and restored at Hartlepool before being towed to Portsmouth where she is open today to the public as a lasting tribute to Watts' talents.

Watts died at Broadstairs in Kent on 11 August 1876 at the age of seventy nine years and although his achievements are clear, the man himself remains a shadowy figure. He never published any account of his work, and no portrait of him is known to exist, so his character remains obscure. He was, however, known to be an autocrat in his professional life but whether this characteristic was also reflected in his private life will probably never be publicly known.

J E Conolly

JAMES MEADOWS RENDEL 1789–1856

Civil Engineer

Son of James Rendel, country surveyor and farmer of Okehampton and grandson of an architect John Meadows FRS, James was born at Thornbury Farm, Whiddon Down near Okehampton in 1789. He passed his youth in the neighbourhood of Teignmouth receiving his education at a country school and was initiated into the practical operations of a millwright by his uncle who resided there. From his father, who had charge of a district of roads, he obtained a degree of familiarity with the rudiments of civil engineering. Then, when he was about eighteen years old he went to London and obtained an appointment with Thomas Telford, who employed him on surveys and experiments for the proposed suspension bridge across the River Mersey at Runcorn.

Five years later he settled in Plymouth and commenced practice of his own being chiefly employed in the construction of roads in North Devon. In September of that year, having commenced on a proposal for a suspension bridge for crossing the Tamar at Saltash, he came under the notice of Lord Morley, who as Lord Boringdon had employed another civil engineer, James Green, some fifteen years earlier. He presented a plan in 1823 for a new road from the White Hart Inn in Okehampton to the Hatherleigh Road and to Five Oaks on the Launceston Road

In 1823 Lord Morley entrusted to Rendel the design of a suspension bridge to cross the River Plym at Laira. When the necessary Act of Parliament was obtained for a bridge, Samuel

Brown who had built the first suspension bridge of iron chain over the River Tweed complained that Rendel had 'made an exact transcription of his plan for the Tamar' and the idea of a suspension bridge was dropped. Roger Hopkins, a civil engineer from Plymouth, proposed a wooden bridge but at the last moment Rendel won the day by presenting an alternative elegant cast iron structure designed for five spans with the ironwork provided by William Hazeldine. He completed his bridge in 1827 and it lasted until 1962. For this fine bridge Rendel gained a Telford medal, having previously been elected a corresponding member of the Institution of Civil Engineers in 1824.

Rendel's experience of suspension bridge design with Telford was not wasted. He appreciated the importance of longitudinal stiffening girders to provide aerodynamic stability, advising on this for the Montrose, Scotland, and Menai bridges. He rebuilt the former in the 1830's and later designed suspension bridges in St James's park, London, and Inverness. It is unclear when he first developed the idea of a deep longitudinal truss as his drawings for the Laira proposal do not exist; the illustrations for his design for Clifton Gorge suggest that this idea may have been in place by 1830.

Soon after the completion of Laira bridge, Rendel constructed some roads for Lord Morley, the Cann Quarry, Plymouth, tramway and a sluice of unusual construction at the northern end of James Green's Chelson Meadow embankment along which Lord Morley had built a roadway to join Saltram House to Laira bridge. He also improved several turnpike roads including a southern road between Sequer's bridge, near Modbury, and Totnes, the road from Plymouth to Cornwall via Saltash and the road from Devonport to Liskeard via Torpoint. In 1826 he constructed Bowcombe bridge over a creek of the Kingsbridge estuary with four masonry arches and an opening span which originally was a drawbridge and where the first use of hydraulic power was applied to machinery to operate bridges.

The Cann Quarry tramway built for Lord Morley was a short branch of 4ft. 6in. gauge (1.38 metres) off the Plymouth and Dartmoor Railway leading to the quarry. A two-span cast iron tramway bridge crosses the River Plym on the Cann Quarry route. The bowstring girders of 7.6 metres span are 2.9 metres apart, have cast iron cross girders carrying a longitudinal sleepered deck for the railway. In 1828 Rendel commenced a survey for a suspension bridge across the river Dart at Dittisham, but this project was blocked by the landowner, James Elton.

Rendel then turned his attention to a proposal for pulling a boat along a fixed chain using steam power and in 1831 a floating bridge was constructed for crossing the river Dart at Dartmouth. The ferry comprised two pontoons side by side with a steam engine between them that hauled on chain using a wheel with sockets shaped to lock onto the links. The chain was adjusted for length by weights at each end in vertical shafts so it would normally lie on the river bed but be sufficiently taut to maintain the ferry's direction of travel. Two chains were used and the wheels, located outside the pontoon, were connected to the engine by a shaft. This, now known as the Higher Ferry, also required 2.4 kilometres of new road to Hillhead, where the road from Brixham meets the Churston to Kingswear road.

After building a similar ferry across the Tamar at Saltash in 1832–1833, which lasted until the suspension bridge was built in 1961, he established another floating bridge across the Tamar at Torpoint in April 1834. This crossing, now known as the Torpoint Ferry, is now so busy that there are three parallel units. Two more ferries were built to his designs, one at Woolston, Southampton, and the other at Gosport. While these two are no longer working, such ferries can be found today at Cowes, Poole harbour and Trellisik near Truro.

In January 1830 he applied for the post of County Surveyor of Somerset, without success, and in January 1831 he offered, in Devon, to do the work for £300 against James Green's salary of £550. Green retained his post but at the reduced salary of £300. During his time in Plymouth, Rendel reported on nearly every harbour in the south west of England, which founded his mastery of this branch of civil engineering on which his fame largely rests. In 1829 he designed the harbour at Par, in Cornwall, and in 1835 he enlarged the sea lock and basin of the Bude Canal.

In 1836 he designed the harbour and breakwater at Brixham in Devon, using the rock obtained from Berry Head; the breakwater has since been lengthened twice. In 1839 he was engaged in preparing various schemes for a railway from Exeter to Plymouth over Dartmoor, via Dunsford, Chagford, near Princetown, Sheepstor and Roborough Down, and in 1841 he constructed the Millbay pier, Plymouth, a work of considerable difficulty, owing to the great depth of water. Here he first introduced the method of construction, since employed with so much success, at the great harbours of Holyhead and Portland. This was the end-tipping of large blocks of stone from railway trucks and the progressive building of the railway on the stone so as to move forward with the construction.

A paper published in Transactions, 1838, earned Rendel a second Telford Medal from the Institution of Civil Engineers and about this time he moved to London, leaving Mr Beardmore as his partner in Plymouth. Rendel then concentrated on harbour works, although he also acted as a consultant on railways in India.

He was President of the Institution of Civil Engineers in 1852 and 1853 and died in November 1856.

James Meadows Rendel devoted much of his life building roads fit for the ever-increasing traffic in Devon. His legacy to the 21st century is evident in many of the 8,800 miles of road (14,200 kilometres) now established in the county.

A B George

THOMAS NEWCOMEN c 1664–1729

Ironmonger and Inventor

Very few individuals have the privilege of a learned society being created in their name but Thomas Newcomen is one of these. The Newcomen Society was founded in 1920 by a number of engineers and others in honour of the man whose name is a symbol of Britain's great industrial movement of the nineteenth century.

Thomas Newcomen was born about 1664 in Dartmouth, Devon, reportedly in one of the quayside houses there and his father was a merchant venturer trading with interests in the ships Mediterranean and Norwich which sailed to all parts of the world.

After an early education, Newcomen probably served an apprenticeship in Exeter before establishing himself in business in Dartmouth as an ironmonger and chemist. This combination seems strange now, but in the 1600's the town chemist simply stored quantities of different herbs and potions along with the recipes showing how these should be combined to cure various illnesses. The ironmonger trade has also changed over the years and in those early days encompassed the activities of someone who not only supplied latches, locks, nails and other items, but who actually manufactured agricultural tools and other hardware. Thomas Newcomen was an accomplished craftsman as well as a trader, as shown by his intricate work on the Dartmouth town clock. It was this practical background that both helped and hindered him later in life.

He was a deeply religious man. At the age of forty one he married Hannah Waymouth, a bride of twenty two who later gave birth to two sons and a daughter.

In the course of his work he frequently visited mines locally and in the Midlands and became familiar with the major problems associated with their drainage plus the heavy cost of using horses to operate the pumps drawing water from the underground areas. The difficulties of draining mines was one of the major problems of the day. Other pioneers, in particular Denis Papin and Thomas Savery, were considering the use of steam in engines to power the mine pumps and Newcomen, in his travels and in conversation with others, was probably aware of these trials. He decided to start work on his own design.

His idea was to manufacture a vertically mounted cylinder with a close fitting piston, then create a vacuum beneath the piston and let the weight of the atmosphere above the piston drive it down. Many believed it was the vacuum 'sucking' the piston down but Newcomen knew that the weight of the column of air stretching thousands of metres upwards, bearing down on the top of this piston, was the source of the power.

With his trading partner John Calley (Caley or Cawley), who was also an accomplished plumber, glazier and craftsman, Newcomen set out to make a working model of his idea. Being a practical man he was determined to design a machine whose construction was within the competence and skills of the craftsmen of the day.

The first consideration in the design was how to create a vacuum in the space beneath the piston. This was achieved by forcing air out of this space with steam, then closing inlet and outlet valves to create a sealed volume. As the steam cooled back to water occupying less space, a vacuum was created between this fluid surface and the underside of the piston. Newcomen simply used steam as a means to create a vacuum. Enormous power was provided by the weight of the column of air bearing down on the piston.

His next consideration was how to speed up the cycle of steam generation, steam injection, and steam cooling. Initially he and Calley constructed around the cylinder a metal jacket through which cold water passed. This was an attempt to cool the steam quickly and whilst it had some effect, it was not the dramatic improvement they were seeking. During one test however, the piston unexpectedly descended with tremendous speed and force. By accident, a minute leak had allowed a small jet of cooling water from the jacket to enter the cylinder and cause almost instant condensation. The leak was eventually traced to the solder that had been used to plug a hole in the cylinder casting. Direct water injection was the breakthrough Newcomen had been seeking and allowed the machine cycle time to eventually reduce to less than six seconds. Newcomen and Calley were both adept at working with iron, brass, tin, copper and lead but ten years elapsed before they completed the design, development and manufacture of a working engine.

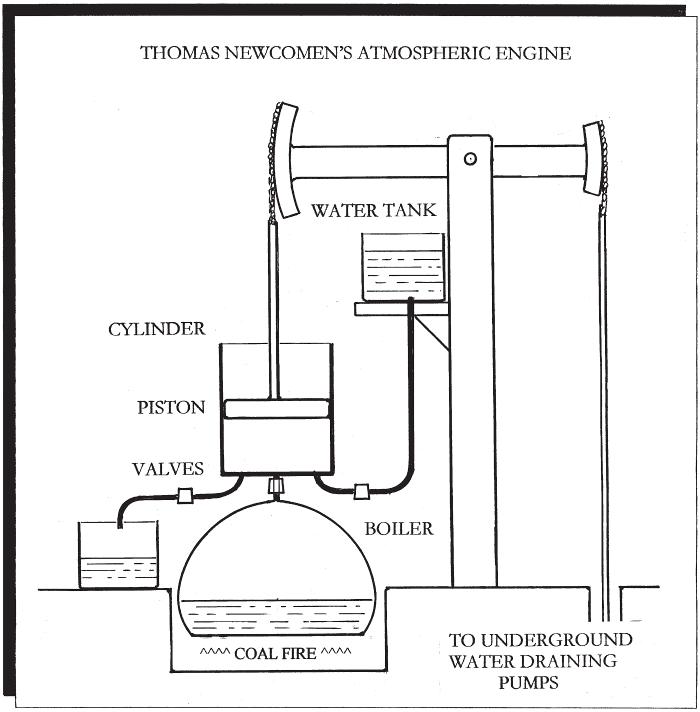
To those in the small scientific world centred on London and the Royal Society it seemed inconceivable that a non-academic man in Devon could have achieved the unique marriage of scientific principles and practical engineering to produce a revolutionary engine. At the time ‘pure’ or academic science received royal patronage and was generally confined to study and laboratory investigations with instruments and apparatus created by skilled horologists.

Newcomen wished to patent the engine’s design but Thomas Savery owned wide rights covering his own invention for a steam engine and, on paper, the two designs could be construed to overlap. Patent laws were notoriously vague and as Savery had connections within the courts, Newcomen decided he would not wish to contest the situation so, when the opportunity presented itself, he became a partner with Savery.

There followed a period of development to connect the vertical motion of the piston to a water pump suitable for mining operations. This was accomplished with a large horizontal beam on a central pivot. One end of the beam was connected to the piston rod and the other to a vertically operating water pump which would be installed down into the mine. For the engine to operate continuously the valves controlling the steam, air and water had to be opened and shut in a precise sequence. Initially this was managed by boy minders but one, named Humphrey Potter, devised a system of latches and strings connected to the overhead beam that helped to make the cycle automatic.

It was the inspiration of harnessing atmospheric pressure to provide the main source of power to drive a practical, reliable, continuously operating and automatic engine that confirmed Newcomen as a genius.

In 1711 he offered to erect his first industrial engine. This first practical installation was at Coneygree coalworks, Tipton, Staffordshire, an area which was the home of many skilled craftsmen, the source of metals and plenty of coal for the engine's boiler. The cylinder was 53 centimetres diameter, 2.4 metres high with a boiler 1.7 metres diameter 1.9 metres high. Operating at a continuous 10 – 12 strokes per minute, the pump extracted 45 litres of water per stroke from a mine nearly 50 metres deep.



This was the first of many successful projects. Engines increasing in size up to 2 metres diameter being erected in Hungary, Sweden, Belgium, France, Spain, Austria, Czechoslovakia, and Germany as well as in Britain. Approximately 1,500 engines were built and the enormous capital investment that was needed for each one pays testimony to the success and reliability of the design. Newcomen and Calley were justifiably proud of their engines and, because of Newcomen's family history of world trading, they had the right combination of commercial ability and practical versatile craftsmanship that ensured success for their endeavours. For more than sixty years following his invention, the engine was still the most powerful and economic for draining mines.

There are not many records of Newcomen's activities during the later part of his life. Most of it was spent in London from where he maintained an interest in his engines and became involved in research and other inventions including one that considered the use of wind power. He died at the age of sixty seven in the house of his friend Edward Wallin in August 1729.

Newcomen received no formal official honour in his life time for his invention and sometimes the engines were referred to as Thomas Savery's or James Watt's. Even overseas laurels were awarded to the builders. He was not however embittered by this lack of recognition being too great and too modest to seek the world's acclaim. The work of creation was its own reward, a satisfaction which no one could take away.

Throughout his life Newcomen enjoyed the reputation of being a perfectly honest man. It has been said that he was the first great mechanical engineer. His engine was tailored to the needs, resources and skills of the time and was the most important single invention of the Industrial Revolution. Improvements were made later, but the first step in any endeavour is always the most difficult. Thomas Newcomen was the pioneer who took this step.

J A Knivett

GEORGE PARKER BIDDER 1806–1878

Civil Engineer

On 14th June, 1806 a son was born to William and Elizabeth Bidder and christened George Parker, the name Parker being his mother's maiden name. The Bidder's lived in Moretonhampstead, a small town on the edge of Dartmoor where William plied his trade as a stonemason. Little did the parents know that George, their sixth child, would become known as 'The Calculating Boy' and one of the most famous civil engineers of the nineteenth century who would bring prosperity to himself and his family.

As a child George gave little indication of his mental capabilities, tending to avoid school and preferring to amuse himself by playing games with marbles and conkers, working out in his head, the various combinations and sequences that arose from those games. His brother John had taught him to count and as a result, he acquired a fascination with numbers that led him to develop mental skills that would prove so beneficial in later life.

The school George attended was run by a local minister who reported that although George experienced difficulty with his writing, he had no problem understanding numbers and doing calculations. He frequently displayed his mental agility by encouraging local people to ask him complex arithmetical problems that he would then solve with remarkable rapidity.

George's father soon realised that he had a child prodigy on his hands and that his son's talent could be of financial benefit to the family. He started to exhibit the boy at local fairs and shows where he was advertised as 'The Calculating Boy' and in due course he travelled further afield, appearing in many towns across the country including London. Charges for admission were made and George's father quickly appreciated the rewards to be derived from these appearances. In the winter of 1816-17 George was invited to display has talents to Queen Charlotte who put to him several numerical questions, no doubt prepared for her in advance of the meeting, which he answered accurately and in record time.

In 1816, two gentlemen from Cambridge who had witnessed one of George's performances, persuaded his reluctant father to allow the boy to attend a school in Camberwell but after a year, his father, unwilling to accept the loss of income, withdrew George from the school. George does not appear to have resented the change and the tours he subsequently undertook no doubt helped to broaden his horizons. He remained cheerful and enjoyed joking with the questioners.

While exhibiting in Edinburgh in 1819, he caught the attention

EXAMPLES OF QUESTIONS PUT TO 'THE CALCULATING BOY'

Q. How many farthings are there in £367,548?
A. (in 15 seconds) 352,846,080

Q. Dividing £24 among 24 sailors so as to give the captains £4, the mates £2, the men 10 shillings and the boys 5 shillings, give the number in each class.
A. (in 2 minutes) 3 captains, 3 mates, 6 men and 12 boys.

Q. Suppose 4,535 grains of sand cover one inch square, how many grains will cover an acre?
A. 28,446,422,400

Q. If a coach wheel is 5 feet 10 inches in circumference, how many times will it revolve in running eight hundred million miles?
A. (in 50 seconds) 724,114,285,704 times with 20 inches remaining.

of Sir Henry Jardine, a prosperous Hong Kong businessman who, together with a group of friends, arranged for George to receive private tutoring and later, for his attendance at Edinburgh University. There he established a great friendship with Robert Stephenson, the son of George Stephenson the eminent railway engineer, which was to last throughout their lives and played an important part in influencing George to pursue a career in civil engineering. George was always grateful to his mentor and repaid his debt to him and Edinburgh by establishing the Jardine Bursary at the university for the benefit of students of limited means.

On leaving university and with the help of Sir Henry, George obtained an appointment as a trainee surveyor with the Ordnance Survey that involving extensive work in Scotland but after two years he moved to Cardiff and then to London. Here he took the next step in his professional career and moved into civil engineering, working as an engineering pupil with Henry Palmer, a well-known consulting engineer and former assistant to Thomas Telford. During this period he worked on surveys for the London Docks and various harbour, railway and canal projects but in order to help support his younger brothers, he also worked as a part-time clerk in the offices of Royal Exchange Life Assurance where his calculating skills were of great benefit to the company.

Following a short period with another firm of engineers where he worked on other schemes in the London area, he joined the practice of his friend Robert Stephenson. This was at the start of 'the railway era' and initially George worked on the London & Birmingham railway gaining valuable experience at a time of great activity when the rail network was being developed throughout the country.

In order that a proposed railway scheme could receive the approval of Parliament, it was necessary to prepare and submit accurate surveys of the intended route together with estimated construction costs for consideration by the appropriate Parliamentary Committee. Such schemes called for careful examination and involved cross-examining the promoters and expert witnesses and it was here that George's talents made their greatest impact. His practical knowledge of surveying, coupled with his prodigious memory and mental skills made him a most effective force when appearing before the Committees. His ability to spot weaknesses and errors in his opponents submission and to present counter-arguments made him such a formidable witness that on one occasion, opposing Counsel objected to his presence stating that 'nature had endowed him with particular qualities that placed his opponents on an unfair footing'.

This was the type of work in which he excelled and he loved the cut and thrust of argument and the analysis of technical problems. Consequently, his main contribution to the expansion of the railway network in this country was through the promotion of schemes rather than their construction and perhaps it is for this reason, that his name is not as well known as those of other famous railway men such as Brunel, Stephenson and Locke. It is a measure of his standing however, that he is portrayed with his contemporaries in the famous painting by John Lucas of 'Conference of Engineers at Britannia Bridge' that hangs in the Institution of Civil Engineers.

Bidder's entrepreneurial flair led him into other fields of development and as his wealth increased, he invested in land as well as a variety of businesses in which he took an active interest. One development with which he became associated was the electric telegraph, a new invention still in the early stages of its commercial development. By introducing it on the London & Blackwall Railway and later on the Norwich & Yarmouth line, he was able to effect economies by introducing single line operation with safe and reliable communication between stations. As the demand for this type of communication increased, he helped to promote and finance the Electric Telegraph Company and the subsequent development of transatlantic cables.

Bidder was responsible for many overseas projects including railway schemes in Norway, Denmark, Switzerland and India and as his reputation grew, he came into contact with many leading dignitaries and Heads of State. He reached the pinnacle of his professional career when he was elected President of the Institution of Civil Engineers in 1860-61.

Although Bidder's main home was in Surrey, he always had great affection for his native County of Devon and having bought a house in Dartmouth his wife Georgina and family of eight children gradually began to spend more time there. He became a member of the Town Council and took an active interest in local affairs, but felt unable to accept the office of Mayor due to his many commitments in London. In 1869 he became the President of the Devonshire Association for the Advancement of Science, Literature and the Arts, a position later held by one of his grandsons. In fact the immediate Bidder family tree contains many distinguished individuals.

The nature of his work meant that he spent long periods away from home but he kept in regular touch with his family. Hard work and dedication were always a feature of Bidder's life and they brought their just rewards so that he and his family were able to enjoy a standard of living his parents could never have envisaged. Together with Robert Stephenson, he made many business and social trips on Stephenson's yacht and at Dartmouth he acquired his own yacht, the equivalent to a personal jet aircraft these days. Always the engineer, his interest in boats and water led to him to assist William Froude, another famous engineer, on experimental work associated with the design of ships' hulls. He was a founder member of the Dart Yacht Club and played an important role in the Club obtaining a Royal Warrant.

Just prior to his death he purchased Stoke House, Stoke Fleming which he planned to enlarge but he died there on 28 September 1878 before the work could be completed. He was buried in the churchyard at Stoke Fleming.

Bidder's prodigious memory and mental agility remained with him until the end and even during the last few days of his life, he was still able to enjoy philosophical discussion and debate with his friends. Bidder's name frequently occurs in the nineteenth century annals of civil engineering and he is remembered in the town of his birth where a mosaic has been laid in the road approaching the parish church that illustrates some of the mathematical problems he resolved as a child. A lithograph of Bidder together with a marble bust can be found in the town's Bowring Library and on 29 May 2003 the Retired Chartered Engineers' Club, Exeter placed a commemorative plaque on the wall of the Parish Council Office in The Square that was unveiled in the presence of his grandson and great-grandson.

Blessed with a wonderful brain, Bidder developed his own method of mental calculation that he explained in a lecture to the Institution of Civil Engineers in 1856. This was complemented by a memory that retained basic information on which he relied when performing complicated calculations and which was probably the result of the games he had taught himself as a child. There is little doubt that his speed of mental computation would compare favourably with today's electronic devices that appear so indispensable for even the simplest of calculations.

A G Banks

WILLIAM BICKFORD 1774–1834

Inventor

The village of Bickington is between Ashburton and Exeter and the town of Simsbury is in Connecticut, USA. They are linked by the family name Bickford; William's early life was spent in the Devon village and Simsbury houses the headquarters of the large and successful Company Ensign-Bickford Industries Inc.

During William's youth agriculture was the main source of Bickington family's incomes with farms which had kept their relatively modest size for many generations. The holdings were generally owner-occupied and the Bickford name had been well established in the area for centuries. In addition to the usual activities of growing crops and rearing animals, the wool trade, initially as a cottage industry, became important in the region and timber also was a valuable commodity with the tree bark being used for leather tanning.

William turned to the leather tanning industry for his livelihood. He became a leather curer and manufacturer with work-shops in Devonport but family ties with Bickington remained strong and letters from his mother still survive advising on his way of life and work, as well as keeping him informed on family matters. Seeking to improve income from the business William moved from Devonport to Liskeard. He took charge also of the first Methodist school in Cornwall and stayed for six years before making moves first to Truro, then to Tuckingmill, near Camborne.

It was in Cornwall, at the heart of the mining industry, that he became aware of the harsh truth of a miner's life – one of misery, danger and sometimes, as the rent-paying tenant of a small damp cottage, squalor, often gaunt from existing on meals of only pilchards and potatoes. Working in the mines sometimes involved wading through chest-high waters having the phenomenal temperature of 100 degrees Farenheit breathing stale air at 90 degrees. There were other great dangers associated with the work and miners suffered the effects of terrible accidents. He met widows who were struggling to raise families, men with blackened faces who were maimed, deformed, blinded and lame.

William, a humane and sensitive man became distressed by the suffering and soon discovered that much of it was caused by the method of using explosive charges. The practice at the time was for the miner at the workface to make a fuse by filling a goose quill or straw with gunpowder before connecting it to the main explosive charge and igniting the fuse end. The method was dangerously unreliable, sometimes due to lack of care so the powder fuse had gaps in it, or the cover was pinched. Sometimes the quills were filled incorrectly, sometimes sand or grit was pushed into the frail tubes, sometimes damp was let in. Any of these things could cause premature explosions before the area had been evacuated, or cause delays, so that a miner approaching the charge to investigate, would receive the full impact of a late blast.

William became determined to design a safer and more consistent fuse and assisted by his son-in-law George Smith performed a series of trials and experiments. One of his first ideas was to place the main explosive material in a parchment tube and attach a smaller one containing powder as the fuse. The assembly was made above ground in conditions better than in the mine itself but despite all their efforts the trials were unsuccessful.

It was during a visit to his friend James Bray, a semi-retired rope maker, that William had the idea that eventually had a profound effect on miners' lives. Bray was spinning some yarn in the ropewalk, walking backwards, twisting it from bobbins to form a strong rope. William thought it might be possible to trickle gunpowder from a funnel into the core as it was being formed and then seal the outside of the rope with some form of coating.

He and George discussed the idea with Thomas Davey, a working miner who was 'a great genius for mechanical contrivances' and together after many experiments they produced a reliable and predictabe fuse. It consisted of twisted yarns round a core of powder, the whole encased by an overlay of more yarns wound in the opposite direction. The powder was trickled in by means of a drum and funnel strapped to the rope-winder's waist. The finished product was passed through a vat of tar to create a waterproof coating that also held the whole together as a strong rope about 12 millimetres diameter and 19.8 metres long. When ignited at one end the fuse would burn at a steady, consistent rate so the miner could simply cut the required length according to the timing needs at the site.

This basic design of fuse remained virtually unaltered for more than a century despite tests on many alternatives and even after the introduction of electric fuses it remained in common use.

William initiated a patent for the 'Safety Fuze', entered into a partnership with Davey and travelled to many mining areas demonstrating the fuse.

Despite the many obvious advantages it was accepted only slowly, partly because miners often had to provide their own materials and the traditional methods cost less than the new. Also there were reported misfires which were eventually traced back to miners using the uncut long fuse to lower tools and equipment down mine shafts as if it were regular rope. This disturbed the powder in the core and caused misfires. William instigated a series of advertisements to explain the importance of proper use and soon the fuses were in great demand. It was some time however before the terrible toll of blinding, disfigurement and death was dramatically reduced.

Tragically William became seriously ill two years after the patent was granted and, completely incapacitated for work, died two years later in October 1834 at the age of 57. He did not live to see the major results of his work, which saved many thousand of lives and greatly improved the wellbeing of miners and their families. His Will included a wish that the business should continue with Davey and Smith plus two relatives in control.

To satisfy the increasing demand for the fuse, a factory was set up at Tuckingmill where it remained until closure in 1961 changing names in the interim period to Explosive Trades Ltd., subsequently the major UK partner in the formation of Imperial Chemical Industries. During its first year of operation, 72 kilometres of fuse were made; a century later the output at Tuckingmill was 170,000 kilometres per year and the total worldwide annual production was 450,000 kilometres. Given that the average length of cut fuse is about 0.5 metre, this production quantity represents an incredible number of individual, safe, controlled detonations.

Overseas manufacturing facilities were in France, Austria, Australia, Hungary and Spain. Another significant development occurred when Joseph Toy became involved with the Company and set up an enterprise in America as Toy, Bickford & Company, later to become Ensign-Bickford Industies, Inc. This organisation pays generous credit to William's achievements in its publicity material on the internet.

In Bickington Church, the scene of William Bickford's baptism more than two centuries ago, is a commemorative slate plaque:

William Bickford
1774–1834
Born in this parish
Inventor of
Mining Safety Fuse

A tribute to the man who, with a very simple invention, prevented terrible maiming and the sudden death of tens of thousands of miners.

J A Knivett

CHARLES BABBAGE 1791–1871

Computer Pioneer, Inventor and Mathematician

Charles Babbage, who is often referred to as 'the father of the computer', was born to a Devon family that was well established in the town of Totnes and part of his early education took place at the Secondary School there. Mathematics interested him and a lot of his leisure time was spent reading books on that subject so, by the time he entered Trinity College, Cambridge he was already a good student.

He enjoyed college life in the company of many friends frequently missing lectures to play games or go sailing on the river. As a new undergraduate Charles had looked forward to having many questions about mathematics answered by tutors but was somewhat disappointed and developed a programme of study for his own reading, mainly the works of foreign mathematicians.

He moved to Peterhouse College and was expected to excel in the final Senate House examinations but graduating without honours dashed any immediate hopes of a fellowship. He was awarded an MA later.

Marriage to Georgiana Whitmore at Teignmouth, Devon, resulted in a family of three boys and a girl and they all lived happily in London on a modest but comfortable annual income of £450, including an allowance from his father.

His home soon became a popular venue for some of the well known figures of the day, Wellington, Melborne, Brunel, Stephenson, Darwin, Dickens and Fox-Talbot the pioneer photographer, all enjoyed meeting there.

He was enthusiastic and inventive, gave series of lectures, became a fellow of the Royal Society and served on the Astronomical Society. He proposed the decimalization of currency, anticipated the role of tidal power as an energy source, and predicted the effects of the end of fossil fuel reserves, all this, nearly two hundred years ago! His many publications concerned subjects such as chess, barometric observations, calculating engines, geology, code ciphers, machine tools, solar eclipses, lighthouses, diving bells, submarines, statistics and the most successful work "On the Economy of Machinery and Manufactures" was later translated into six languages.

Always a prolific experimenter with a love of instruments and mechanical devices, his inventive spirit at school had led him to make a pair of hinged flaps which, attached to the feet, were supposed to allow a walk across the waters of the River Dart. They didn't work, and he got wet!

Later, more successfully, he designed and constructed the first known ophthalmoscope for examining the interior of the eye. Among his other many ideas were a fail-safe coupling for railway carriages, a form of camper-van and a pen for drawing dotted lines. Another idea was for an overhead rope-way system for postal deliveries throughout Central London; the country's first e-mail system!

Charles helped his friend Brunel by designing a machine to record automatically the motions of a carriage travelling on the wide gauge railway. The machine produced charts on many miles of paper and was really the ancestor of the 'black box' now carried on modern aircraft.

He was sometimes critical of the Government even suggesting on one occasion that it was 'incompetent to understand the merit either of the mechanical or mathematical'. He also criticised the Royal Society and the conduct of its officers and his comments affected relationships with some influential individuals.

However, Charles' lasting fame is based upon the idea of automatic calculation. In a period where a lot of thought was being given to relieving the manual effort of work, his calculating machine addressed the idea of relieving mental effort; it was the

Engines, their design and construction, that really dominated his life.

The dawning of the idea of calculating by machine came during a meeting with his old friend John Herschel when they were checking some new astronomical tables together. At that time published tables of numbers were used by scientists, engineers, architects, builders, merchants and bankers. Also for other commercial activities including navigation where errors resulted in many shipwrecks and tragic loss of life. Tables were produced by teams of 'computers', people who progressed manually through many operations to finally record the results; inevitably this process was prone to human error. The numerous mistakes he and John discovered whilst checking the tables prompted the wish that the figures had been produced 'by steam', in other words mechanically.

Inspired by this intellectual challenge he worked so hard on it that his health suffered as a result of the sustained mental effort and dedication to the task. Eventually he designed and later constructed a small experimental version of his Difference Engine, so called because it was based on the 'difference' principle of calculation. Then, following a favourable recommendation by the Royal Society and influential supporters, Government finances were secured for his proposal to construct a larger fully engineered machine, The Difference Engine No.1.

The design specified tens of thousands of parts including vertical shafts carrying meshing gears, all to be made with a degree of precision that was very unusual at the time. The whole structure was to be about 2.4 metres high, 2.1 metres long and 0.9 metre deep, powered by an operator turning a wheel. The demand for such high precision created real problems but, on the recommendation of his friend Brunel, Charles employed the very skilled engineer and draughtsman Joseph Clement and a period of concentrated work ensued. Tragically this was interrupted three years later by four family events that occurred more or less at the same time; Charles' wife and a new born baby, his second son and his father all died. He was inconsolable and embarked on a journey around Europe which lasted a year.

During these travels he met prominent scientists, visited workshops and talked to craftsmen as part of a study of engineering manufacture. The Engine Project was entrusted to John Herschel.

After Charles returned, the Treasury advanced further money and Clement assembled a small section of the Engine as a demonstration piece which worked perfectly; it ranks among the most celebrated icons in the prehistory of computing.

One year later Clement stopped work following an argument concerning financial compensation, patents and right of ownership. Sadly, although most of the parts for the calculating section of the Engine were complete, construction was never resumed. After the last payment to Clement the Government's outlay had totalled more than £17,000. Compare this sum with the £800 construction cost of a fully operational steam locomotive at the time.

The collapse of the project after a decade of design and development was the major disappointment in Charles Babbage's scientific life and he was never fully reconciled to the sad outcome. Occasional correspondence for support from successive Governments ensued and eventually an interview was granted with the prime minister, Sir Robert Peel.

By that time Charles had thoughts for a simpler Difference Engine and had ideas for a more sophisticated Analytical Engine. He had hoped to recieve new funding for the new designs but the meeting with Peel did not go well; they argued and the meeting ended acrimoniously.

Charles took two years to design his Difference Engine No. 2, an elegant and more efficient version of its predecessor. As before, it incorporated vertical shafts each carrying many gears but with an integral printing apparatus to press calculated results into paper maché or soft metal. Plans were offered to the Government but no finances were received.

The Analytical Engine, unlike the Difference Engine, was capable of calculating virtually any mathematical function and could be programmed for mathematical operations in any sequence. It was capable of choosing alternative actions depending on the value of a calculated result and also separated the section holding numbers, called the Store, from the section processing them, called the Mill. A Store was 6.1 metres long and the Mill 4.6 metres high, 1.8 metres diameter. The machine used punched cards, a technique borrowed from Jacquard looms controlling the patterns of woven threads by allowing certain rods of a bundle to poke through card holes and operate different parts of the mechanisms.

Charles became obsessed with increasing the speed of calculation and devised an 'anticipating carriage', a brilliant technical coup which acted as a psychological boost to his confidence. However only sporadic and inconclusive efforts were made to construct a full-scale Analytical Engine.

During the course of his life Charles' outspoken views had not been well received by certain individuals and not everyone in a position of influence was convinced of the Engines' merits. It may perhaps have been a consequence of this that Charles was excluded from the organization of The Great Exhibition of 1851 which was the largest industrial manufacturing spectacular yet staged. This exclusion was, for him, an affront to his self-perception as a statesman of the industrial movement and subsequently he became increasingly saddened by some of the events in his life. Lonely, he died on 18 October 1871 at his house in London.

He had once remarked that he would like to return in five hundred years time with a guide to explain all the scientific discoveries made in the meantime and certainly would have been enthralled to see that the calculating section of Difference Engine No. 2 had been completed at the Science Museum, London in 1991, the bicentennial anniversary of his birth. His status as a 'computer pioneer' may be based mainly on the concept of the Analytical Engine. His reputation as the 'father of the computer' perhaps rests less on the impressive mechanisms he designed, but more on the dedicated pursuit of the ambition to relieve human intellectual effort with machine operations.

By any measure, Charles Babbage's enthusiasm, dedication and life achievements are remarkable and inspirational.

J A Knivett

FRANK WHITTLE 1907–1996

Engineer, Inventor and Pilot

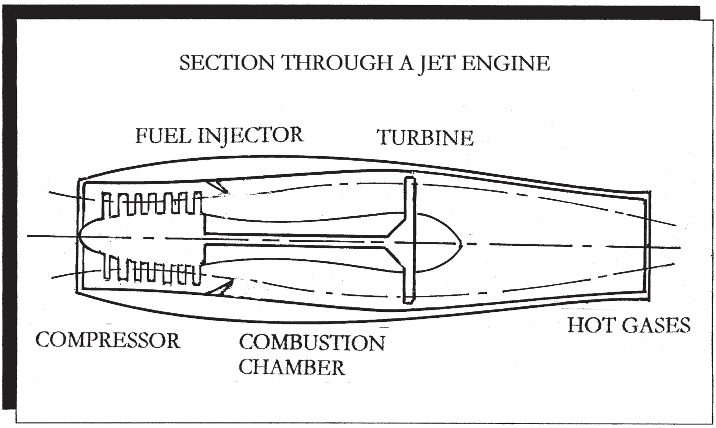
What do you want to be when you're grown up? An age-old question but a hundred years ago, and for many years since then, a boy would commonly answer 'an engine driver'. A girl might have said 'a nurse' and quite a number still would, thank goodness. Few however would now choose to drive railway trains. The appeal of controlling a heavy hurtling steam locomotive has now disappeared except on a handful of historically reserved private tracks as between Paignton and Kingswear.

Today's equivalent occupation for ambitious imaginative boys, and of course girls too, might be to captain and pilot a commercial airline 'Jumbo' or an A380 Airbus or a supersonic military plane. The existence of that possibility owes more to one English man than to any other single individual. He lived from 1907 to 1996. His name is Frank Whittle. He was a professional Engineer, a great inventor and an RAF pilot, and he lived in Chagford, Devon, from 1963 to 1976.

Until Whittle came along aircraft were propeller-driven with the power coming from internal combustion piston engines. Whittle revolutionised aircraft by inventing and developing gas turbine engines, both jet engines and turbo-props. We all now take for granted the hundreds of thousands of civil and military aircraft flying every day all over the world. Before Whittle's first experimental jet aircraft flew in May 1941 there were none. In less than one lifespan world travel has been changed from thousands voyaging by ship, often for weeks on end, to millions flying between countries and continents in hours. Of course, many people have helped to bring about this astonishing change but it was Whittle's imagination, inventive genius and engineering skill which launched the transformation.

Whittle's father owned a small engineering business in Leamington Spa, near Coventry, where the family lived. Frank won a scholarship to Leamington College but he was not a star pupil academically for he was too interested in aeroplanes and flight. When he was sixteen, he won an apprenticeship with the RAF at Cranwell. There he took great interest in aircraft design and his final coursework project in 1928 was an essay on 'Future Developments in Aircraft Design'. He concluded that a new type of power plant was required to increase fighter aircraft speed from about 150 mph to 500 mph. That was a fine target but he did not then appreciate how it could be achieved. The idea of direct jet propulsion did not occur to him until he had learned to fly and been posted with a Commission to a flying instructor's course as a trainee.

Whittle was a Chartered Engineer. He acquired that status after first qualifying as a pilot in the RAF and before being sent on a Service Engineering course and, in 1934, to Cambridge University to undertake an Engineering Degree. Even before he was transferred from flying to technical duties Whittle had made his first



masterly invention. It was to propel an aircraft by a hot gas jet produced as the exhaust from a gas turbine. The other function of that turbine was to drive through a common shaft an air compressor; the outlet from the compressor led to a combustion chamber and thence to the turbine.

Inorder for this concept to work, the compressor and turbine designs available at the time had to be improved greatly and significantly better heat-resistant materials had to be developed, particularly for the combustion chamber and for the turbine blades.

Whilst he was still an RAF Officer pre-war Whittle was allowed to form a Company, Power Jets, to work out solutions to all the practical problems and several young Engineers were directed to help him. One or two industrial firms were given sub-contracts by Power Jets not only to find solutions to the technical problems but also to build prototype engines. Over the next decade, British Thomson-Houston, Rover, Metropolitan-Vickers, de Havilland, Shell, Bristol Engines and Rolls-Royce were introduced into the effort to turn the original ideas into a practical proposition.

Because the project was being undertaken in wartime much secrecy was involved. The first jet aircraft, for example, was transported cross country on a truck under wraps. Since the general shape gave away the fact that there was an aeroplane under the covers, a false propeller was added to the front to conceal the form of the air intake. The secret was well kept until the flight of a prototype aircraft was achieved, thereafter it became inceasingly difficult to pretend all was normal as the uniquely fast aeroplane with no propeller flashed around the Midland skies. Success meant that experimental design and development gave way to factory production. Before the war ended in 1945 a new twin-jet-engined fighter, the Meteor, capable of more than 600 mph, was in squadron service with the RAF and since that time an increasing majority of aircraft built around the world have been jet-propelled. All primarily based on that first, and several other, inventions made by Whittle and the Power Jets team.

His great idea of direct jet propulsion then came to him and he shared his thoughts with the Instructor who taught him blind flying. This was an amazing contact at a crucial time for the Instructor, Flying Officer Patrick Johnson, was a young qualified Patent Attorney unable, in those days, to practise his profession until he became twenty five years of age. Johnson explained to Whittle that making an invention is only the first half of the story. Protecting one's right to it legally is at once essential and has to be properly done. Whittle was convinced. Johnson was willing to attend to all the formalities and for the next ten years and more the two worked together so that all the inventions of Whittle and of his Power Jets colleagues were protected by patents thoughout the industrial nations of the world.

Those inventions were concerned with all aspects of design and operation of the three main components of a jet engine, namely the air compressor(s), the combustion system and the turbine(s). Whittle personally made decisive improvements to compressor and combustion chamber design. He also made a most imaginative change to the basic layout of jet engines so that today they are almost all of a 'by-pass' type. In this concept, dating from 1936, the air entering the engine is divided so that some passes through the basic compressor, combustion and turbine stages but a greater part 'by-passes' most of the compressor and the core engine rejoining the engine stream in the propulsive jet. Such a design has a considerably better propulsive efficiency than is obtainable with a 'straight-through' jet, which is an important consideration particulary for commercial aircraft. Higher efficiency there means less fuel is needed, range is increased, operating costs and fares can be reduced.

When Whittle first put forward his ideas not many supported them. It was true that to carry them into effect there would need to be a considerable support in well directed research and development effort. Gradually, and then with more aceptance under wartime pressure, greater priority was given by those in authority to Whittle and to the Power Jets company. Once the practicability of jet propelled aircraft had been demonstrated, the importance and extent of the jet revolution became obvious.

Under wartime conditions great inventions of this kind were shared between the Allies. Whittle found himself sending engine drawings and performance calculations to the US Government Agencies so that US industry could go into jet engine production. Whittle himself was sent to the USA to explain his work and his plans. A contract was placed by the American Government on the General Electric Company to make a first batch of engines to the British drawings. The foyer of the GE factory office at Lynn Massachusets, near Boston, contained, and probably still does, a display of one of those engines. The enormous resources of the USA meant that the US Air Force as well as the RAF had jet fighters in service before World War II ended.

By 1946 the jet engine 'baby' had outgrown its Power Jets parent. Arrangements were made for that company to concentrate on research and development, on disseminating gas turbine technology and in world wide patent protection and licensing. Whittle himself had been promoted to Air Commordore RAF and knighted but it was difficult fo him to be incorporated into any Service or Industrial structure. He retired from the RAF as his wartime work and the enormous range of his innovations became widely known.

Honours of all kinds flowed his way. In his own words '. . . at home, I have a large collection of gold medals . . .' In this country he was made a Fellow of the Royal Society and the Royal Commission on Awards to wartime Inventors sponsored a grant to him of £100,000 tax free, an enormous sum in those days and the largest amount ever paid. In later years HM the Queen personally made him a Member of the 'Order of Merit', a very great honour indeed.

Whittle's later life was calmer and quieter than the pre-war and wartime years had allowed. For example, the twelve years he spent living at Chagford on the edge of Dartmoor were a period of his life when he managed to keep himself out of the limelight and certainly out of notice of the media. He was not, however, a recluse; he made and kept friends and never lost touch with his former Power Jets' colleagues. From time to time he suffered ill-health but apart from those periods he continued to take great interest in the aircraft industry and also in occasional parallel ventures in co-operation with the Shell Company and with Bristol Siddeley Engines Ltd.

Whittle's greatest contributions had all come, however, in the first half of his life. It was then that he was able to make fundamental technical proposals, primarily through a gift of imaginative perception. His proposals and inventions often came in the form of 'obvious' solutions to problems which had defied all efforts of others, sometimes for years. Such an ability is not always welcomed by those 'others' and he had suffered more than his fair share of their jealousy. It did not always help his reputation with his professional colleagues that often he simply could not comprehend their inability to see what he could see. Also he was almost always right in his technical diagnoses. To err is human, to be uncannily right most of the time is hard to forgive!

During the wartime years Whittle was working under great pressure in his unique capacity as a serving RAF Officer who was simultaneously bringing about a technological revolution within an established industry. Every day brought problems of all kinds. Some were technical, others were human and personal and much time was occupied coping with the Civil Service bureaucratic machine. A ridiculous example of the latter is found in the lengthy correspondence he exchanged with the RAF Personnel Branch about the appropriate daily subsistence allowance to which he was entitled when he was sent to the United States. The rates for Washington and Boston were different, so how did he divide his time? There were not many more important people sent to co-operate with the Americans at that time but he had to abide by all the rules and even as a Wing Commander had to await his turn in the queue for a place in a Liberator aircraft flying across the Atlantic!

From these comments it will be realised that although Whittle was a 'Great Man' of abnormal ability he was not absolved from everyday difficulties of life. Nevertheless his training as a professional engineer provided a solid foundation for his career. He chose to accept the discipline of study and the acquisition of relevant experience over several years to achieve the competence and status of a Chartered Engineer. Those acquiring that recognition in the community are all engaged in the application of science to the design, development and operation of machinery, of technical equipment and of construction works. There are various branches of Engineering in which one can choose to specialise. In Whittle's case it was Aeronautical. For others it might be Electrical, Mechanical, Structural, Transport, Manufacturing. Without fully qualified men and women working in all these fields of activity our lives would be much the poorer and less interesting. And every young Chartered Engineer has the prospect during his working life of making significant changes to an industry or even to transforming life for great numbers of people.

Air Commodore Sir Frank Whittle OM FRS FREng did! We are all his beneficiaries.

R C Orford

ACKNOWLEDGEMENTS

Information contained in the preceding chapters has been obtained from many sources and members of the Retired Chartered Engineers' Club are deeply indebted to those who provided valuable assistance and to those whose work has been incorporated.

These include – D H Brown, D K Brown, R Burt, E F Clark, Z Cowan, J Devey, W Gore Allen, W Felkin, S Hands, A Heather, R Larne, J McKay, P J Nahin, J Naish, J Pike, J Potter, W Rolt, S Smiles, L J Taylor, M Turner, G Varley, Pamela Vass, K Wall together with members of the staff at Budleigh Salterton, Chard, Exeter, Honiton, Newton Abbot, Plymouth, Tavistock, Tiverton, Totnes, Truro and Sidmouth libraries and museums.

Other facts were obtained from the Biographical Dictionary of Civil Engineers, Devonshire Association, Institution of Civil Engineers, Institution of Mechanical Engineers, Mortenhampstead Local History Society, Newcomen Society, Oxford Dictionary of National Biography, Royal Institution of Naval Architects, Royal Naval Submarine Museum, University College London and Internet sites.

Further information concerning the individuals featured in this non-profit-making book may be retrieved via Internet 'search engines'.

THE FUTURE

The achievements of just a few individuals have been described in this book and although they lived some time ago their successes have had an enduring effect on today's world.

Now, in the twenty-first century, just as in previous centuries, major pioneering projects demand the expertise of members of teams and these are invariably led by individuals with ambition, drive, imagination and enthusiasm.

Whether the project is an impressive structure or a delicate piece of medical equipment, each team member contributes to the final result. Individual members may have knowledge in the fields of geology, aerodynamics, metallurgy, electronics or another discipline and a successful venture also demands project control provided by expert planning and scheduling.

All these activities offer job satisfaction, challenges and opportunities, and all can contribute to make the world a better place and transform peoples lives.

Information concerning technical career options, qualifications and rewards is available from Libraries and Career Advisors as well as the Engineering Council's web site at www.engc.org.uk.

The writers of this book sincerely hope it has stimulated an interest in engineering and if it has inspired career aspirations in this profession then it has fulfilled its purpose.