BRUNEL COLLEGE OF TECHNOLOGY

THE

BRUNEL LECTURE

1958

ISAMBARD KINGDOM BRUNEL

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FIRST
BRUNEL LECTURE

on

I K BRUNEL

delivered at the College on
22nd January, 1958

by

L T C ROLT

L T C Rolt was born in 1910 and educated at Cheltenham College. Subsequently he served a five-year engineering apprenticeship. His published works include fiction, philosophy, and topography, but his chief interest has always been to give the history of the Industrial Revolution and its engineering legacy an imaginative and literary shape. His most recent works are biographies of Isambard Kingdom Brunel and Thomas Telford.

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BRUNEL

Isambard Kingdom Brunel was not only a great engineer, he was a very great man. It was because I felt that his stature was not sufficiently appreciated or his memory honoured as it should be that I decided to write his biography. You may imagine then how delighted I was when I heard that this new College of Technology, standing as it does so near Brunel's Great Western Railway, had been named after him. I was even more delighted when your Principal told me that it had been decided to make Brunel the subject of the first Annual Brunel Lecture. I esteem it a great honour and privilege that I should have been invited here to deliver this first lecture.

I do not propose to give you a full account of Brunel's career for that would take too long. Although he died at the age of fifty-three he managed to cram an almost unbelievable amount of work into his comparatively short life. But I want to tell you enough about the man and his achievements to enable you to form a picture of him in your minds, and I want to do this not merely out of pious regard for his memory but because, as I hope to show, I think there are some valuable conclusions to be drawn from Brunel's story.

I expect most of you have heard something of two of Brunel's railway exploits, the adoption of a broad gauge of 7ft for his Great Western Railway and his experiment with the atmospheric system of traction on the South Devon Railway. The first was a technical triumph but commercially unsound, while the atmospheric experiment was a failure on both counts. In this connection I want to read you a short extract from an Obituary of George Stephenson which appeared in the Civil Engineer and Architect's Journal for December, 1848.

If in anything Stephenson showed a littleness of feeling it was about Brunel. He (Stephenson) was too much given to do as others did about him, to look upon railways and engines as belonging to himself alone and that no one else had a right to meddle with them. Forgetting that he himself was the follower of Trevithick, Jessop and Chapman, the helpmate of James, Birkenshaw, Booth and others, he could not bear coolly anything which was not of his school. He never forgave Brunel for taking another gauge. In a speech at Tamworth on the occasion of the opening of the Trent Valley Railway, George Stephenson said that he considered the atmospheric 'humbug from beginning to end. But,' he went on, ''it is not the only humbug; the Broad Gauge is another misconception just as erroneous.' " "But," the writer of this article concludes, "whatever Stephenson might choose to say. England owes much to Brunel for spurring on Stephenson; for had it not been for the Great Western we should never have got the great speed which we now have."

That conclusion is, of course, perfectly sound. Mile-a-minute speeds became commonplace on the broad gauge Great Western at a time when 30 miles an hour was considered good going on the narrow gauge. Indeed the superiority of the broad gauge express train can be compared with that of the Comet jet air-liner over its piston engined predecessors, and there was no greater stimulus to railway progress in the 19th century than the performance of the famous Great Western flyers between Paddington and Exeter. They were the first express trains in the world.

But my object in quoting this extract is not to extol Brunel at the expense of George Stephenson; it is to emphasise the completely contrasting characters of these two great engineers. Stephenson was, of course, a much older man. He was one of that school of self-made, self-educated engineers of humble origin like Brindley, Telford and Rennie who between them pioneered the industrial revolution. That great technical revolution could not have begun in any other way. Where there was no accumulated fund of technical knowledge and data, the first tentative steps forward could only be taken by practical craftsmen working empirically, that is to say by observation and experiment. Although he was a practical man, Stephenson had little inventive genius and was not a bold experimentalist. But he was extremely shrewd and bard-headed and the secret of his success was his ability to weigh the merit in the inventions of others and to combine those merits with practical and commercial success. In the case of the first crude steam locomotives, Stephenson was able to separate the technical wheat from the chaff and so succeed where a far more original genius like Richard Trevithick had failed. But once he had proved that the locomotive railway was a practical and commercial proposition, Stephenson pursued a policy of cautious conservatism which is characteristic of men of his type. Whenever the solution of a problem satisfied him, that solution established in his mind a kind of sacred precedent from which nothing would induce him to depart. It was in this fashion that Stephenson came to look upon railway construction as a mystery to which he alone held the key and over which he presided with Papal infallibility. It is easy to understand, therefore, how Stephenson would resent the meteoric appearance in the railway firmament of such a personality as Brunel.

For whereas Stephenson spent his life establishing technical precedents, Brunel dedicated himself to their demolition. For him the first thing to do with any precedent was to question its right to exist. In fact Brunel regarded safe precedents as so many sandbags holding down the balloon of the mind; if you wanted to rise to the heights of achievement you must throw them overboard and this is just what he did throughout his spectacular career. Once again I want to emphasise that in making this distinction I am not decrying Stephenson. The point I wish to make is that Stephenson and Brunel represent in excelsis two contrasting types, each an essential foil to the other. All scientific and technological development requires the caution, the patient thoroughness, the faith and the shrewdness of a Stephenson no less than the sceptical, adventurous and daring spirit of a Brunel and, as was the case with the development of railways, solid achievement is the product of these perennially contrasting types of mind. The fact that they often strike sparks from each other in the process is all to the good.

As soon as the industrial revolution was fairly launched the store of scientific and technical knowledge began to accumulate very rapidly. When the first creations of the practical pioneers became, as they so soon did, the subject of scientific theory and calculation which would form the basis for future developments, so it became obvious that these pioneers would be succeeded by a generation of engineers who possessed a far wider range of technical equipment. Brunel was of this generation. So also was Robert Stephenson, for George saw to it that his son had the education which he had lacked. Consequently the younger Stephenson had much in common with Brunel and although professionally they were always in opposition, privately they became close friends.

Like George Stephenson, Brunel's émigré French father, Sir Marc Brunel, belonged to the pioneer generation of engineers whose approach to problems was empirical and who acquired much of their knowledge by experience. Nevertheless he came of yeoman rather than peasant stock and in his youth in France he received a better education and training than did the elder Stephenson. Marc Brunel first achieved fame in this country through the series of machines which he evolved for making ships blocks at Portsmouth, one of the earliest examples on record of a completely mechanised system of production. In the designs for these machines, Marc Brunel most probably introduced to England from their French source the elements of engineering draughtsmanship as we know it to-day. He therefore had a great deal to give his son, but in addition to this legacy, young Brunel studied at the College of Caen in the Brunels' native Normandy and then at the Lycée Henri Quatre in Paris, which was then famous for its mathematical teachers. He followed this with a period of apprenticeship in the Paris workshop of Louis Breguet who, as a maker of watches, chronometers and scientific instruments, was one of the world's greatest craftsmen as any horologist will tell you. Brunel then returned to England where he began to assist his father in his practice as a consulting engineer. But we also know from Brunel's own admission that he spent a great deal of his time in the shops of that famous engineering firm, Maudslay, Sons & Field of Lambeth where, he said later in life, "I probably acquired all my early knowledge of mechanics."

I have given you this chapter and verse about Brunel's education for a particular reason. This is to contradict the impression some people seem to have that by comparison with other engineers of his generation Brunel was a kind of inspired amateur, a technical dilettante who set about realising his grand ideas in the old empirical way and only discovered the snags later. I think his very different social and family background, coupled with the fact that he brought to the profession the imagination of an artist, was probably responsible for this notion. In fact there was nothing of the amateur in Brunel. No engineer of his day could have had a better training both in the practice and the theory of his profession. His sketch books and notebooks, which are preserved in the Bristol University Library, give us some fascinating glimpses of the way Brunel worked. The artist in him would dash off quick sketches of new ideas, but then the cool intellect of the technician would decide whether or not such an idea was worth pursuing. If he decided it was, he would work out every detail with the greatest care. And I mean every detail, for his versatility was extraordinary and there was then no problem in civil or in mechanical engineering that he was not equipped for and eager to tackle.

When he was only twenty, Brunel was resident engineer for that extraordinarily difficult work the Thames tunnel, and the series of disasters which occurred during construction gave him his first chance to display two of his outstanding qualities - refusal to admit defeat and a complete lack of fear in face of danger. From a constructional point of view the tunnel was remarkable in two ways. It was the first in which the excavation was carried on within a protecting shield which was designed by Marc Brunel. The other unique feature was the way in which the vertical shafts on each shore were sunk. The shafts were built of brick to their full height above ground, this brickwork resting upon an iron curb or shoe. The ground beneath the shoe was then excavated so that the brick cylinder sank into position by its own weight. Such procedure is now a commonplace of civil engineering, the only difference being that nowadays we use monolithic concrete construction instead of brickwork, but in 1825 it was entirely original. I mention this to show what a legacy of originality Brunel inherited from his father.

On this tunnel Brunel was working under his father. The first major work which he undertook on his own account was the Clifton Suspension Bridge. Here he became involved in a conflict with another famous engineer of the pioneer generation- Thomas Telford-which foreshadowed his later clash with George Stephenson. The design for the bridge was put out to competition and the ageing Telford - he was then over seventy - was asked to adjudicate. Now Telford had recently experienced trouble with his famous Menai Suspension Bridge. Gales sweeping through the Menai Straits had set up excessive movement in the suspended platform, so much so that damage had been caused and Telford had been compelled to alter his construction in several respects. As a result of this experience Telford came to the conclusion that the 600ft. span of the Menai was the safe maximum and that no suspension bridge of greater span could offer sufficient resistance to lateral wind pressure. For this reason he rejected all the four designs which Brunel had prepared for the competition because they had spans varying from 870 to 916ft. Telford's attitude towards his bridge was, in fact, exactly the same as George Stephenson's toward his locomotive railway - having arrived at a successful design by a process of trial and error he refused to believe that anyone could improve upon it, least of all a young man who had only built bridges on paper. In fact Brunel had visited the Menai, studied the bridge closely and found an answer to the snags which had troubled Telford. He designed a better type of suspension chain and he arranged the suspended arc of the chains in such a way that at the centre of the bridge platform the suspension rods were extremely short. This made his designs much more resistant to lateral pressure. He defended his designs so vigorously that a second competition was held for which Telford's own design was submitted. In this, Telford's design was rejected and Brunel's accepted. The moral of this little story is salutary and obvious. It is that you can never complacently sit back and regard your achievement as perfect. If you do, you can be certain that somebody else will come along and show you just how wrong you were. Brunel taught George Stephenson the same lesson except that in this case he could not prevail. The standard gauge of 4ft. 821ins. had been too widely adopted by the time Brunel was able to demonstrate the advantages of the broad gauge, otherwise our railway history might have been very different.

If Brunel's dramatic entry into the railway world came too late to conquer that world for his broad gauge, that was not his fault. He applied unsuccessfully for his first railway post - to the Newcastle & Carlisle - in 1830, the year that the Liverpool & Manchester Railway was opened, but it was not until 1833 that he was appointed engineer of the Great Western and two more years went by before construction began and he was able to put his theories into practice. Meanwhile railways were extending so rapidly that this delay, short though it may seem, was fatal to the broad gauge. Railway construction at that time was a monopoly of engineers of the Stephenson school and it is really not surprising that railway promoters should have hesitated to employ a young man who had not been trained in that tradition. But when, through sheer pertinacity, he broke through this barrier, his original ideas shook the railway world to its foundations and in a very few years his fame ranked with that of the Stephensons. If he had been more commercially minded he might have bowed to the superior weight of the opposition and adopted what he and his supporters rudely called “the coal wagon gauge,” but he was a technical perfectionist and was convinced that the superiority of his 7ft. gauge in speed, stability and comfort was so great that it must ultimately prevail. Technically, the broad gauge achieved all he claimed for it, but with so great a mileage of narrow gauge line already in being it was foredoomed to failure for the simple reason that it is very much simpler and cheaper to narrow the gauge of a railway than it is to widen it. All the same, the broad gauge was a magnificent failure which is more than can be said for Brunel’s atmospheric railway experiment in South Devon.

As I expect most of you know, the principle of the atmospheric railway was that the trains were hauled along by a motive carriage equipped with a piston which ran in a pipe laid between the rails. A series of pumping stations placed at intervals along the line exhausted the pipe with the result that the trains were driven along by atmospheric pressure. Obviously there had to be a continuous slot in the top of the pipe to allow for the passage of the arm which connected the piston to the carriage. This slot was sealed by a continuous leather-jointed flap valve which was opened and closed again by rollers before and behind the piston arm. This, as you may imagine, was the Achilles heel of the invention. Exposure to weather and wear and tear soon played havoc with it and as soon as it ceased to seat properly, working became most inefficient.

Many people have wondered why a brilliant engineer like Brunel ever fell for such a scheme, but was it really so surprising? I think I can understand how it appealed to him. Brunel realised the advantages to be gained by transferring the source of power from the track itself to the track side and that is precisely what we have done, for similar reasons, on our electrified lines. But Brunel saw in the atmospheric system another advantage which even an electrified line cannot match. The atmospheric motive carriage carried no mechanism other than the propelling piston and it needed no adhesive weight. It could therefore be as light or lighter than the rolling stock it drew and Brunel envisaged an immense saving in the capital and maintenance costs of permanent way and bridges. Railways, in fact, could be built far more cheaply if they could be freed from heavy axle loads and the hammer-blow of steam locomotives. In those days when even the steam locomotive was in its infancy, the silent, effortless performance of the atmospheric must have been magical so that one can understand why Brunel thought it worth while to wage his determined but unsuccessful battle with the technical snags in the scheme. Given modern materials the chief difficulty with the continuous valve might have been overcome, but it was Brunel’s fault that his schemes so often asked too much of the technical resources of his day. To achieve practical success an engineer must accept the limitations of the means at his disposal.

Brunel’s reputation withstood the failure of the atmospheric remarkably well, very largely because he was absolutely honest about it and never tried any face-saving tactics. As soon as he realised that it could not be made a practical success he bluntly told the South Devon Railway Company to scrap it even though many people, including the Chairman of that Company, still believed in it. I think it is not too much to say that had it not been for the courage Brunel displayed in frankly admitting this technical defeat we might never have had the Saltash Bridge. For it impressed the South Devon and Cornwall Railway Companies so much that they continued to employ him as their engineer, whereas if he had procrastinated and tried to justify himself I think it might well have finished his career, at least in the West Country.

The Saltash Bridge was Brunel’s last great railway work; in fact it was not finished until just before his death. I don’t propose to describe its construction in any detail but only to mention two points of particular interest about it. The first is that for building the underwater portion of the great central pier in the Tamar. Brunel designed and used a large compressed-air caisson. He first used compressed air for sinking the piers of his bridge over the Usk at Chepstow which was a kind of dress rehearsal for the larger work at Saltash. At Chepstow the piers were large cast-iron cylinders which themselves formed the caissons, the air locks being fitted on top of them. At Saltash the pier was built of masonry within a caisson which was constructed in two halves so that it could be removed afterwards. Nowadays, in similar circumstances, instead of masonry the caisson would be filled with reinforced concrete and left in situ. So far as I know these are the earliest examples of the use of compressed-air caissons in this country and when I say that even to-day some civil engineers hesitate to use such caissons but prefer to sink monoliths by weighting and grabbing from within, you will appreciate the pioneer quality of Brunel's work over a century ago.

The other point I want to make about Saltash is that as a design it was a much finer and more economical structure than Robert Stephenson's Britannia Bridge over the Menai which was then the only other work of comparable size in Britain. The Britannia is a very impressive bridge, but Stephenson's idea of carrying the railway in huge wrought-iron tubes of rectangular section, though perfectly effective, was a clumsy solution; it was like using a sledge hammer to crack a nut.

At the same time that Brunel was designing the Saltash Bridge he was also planning the hull design of his immense ship the Great Eastern and in connection with the latter he wrote:

"The principle of construction of the ship is in fact entirely new if merely from the rule which I have laid down and shall rigidly persevere in that no materials shall be employed on any part except at the place and in the direction and in the proportion to which it is required and can be usefully applied for the strength of the ship and none merely for the purpose of facilitating the framing and first construction." Exactly the same principle guided him in the design of the Saltash Bridge and it was thanks to a far more accurate knowledge of the stresses involved that he was able to build a much more economical bridge without any sacrifice of strength or durability, as time has shown, for it stands to-day exactly as he built it. I have made this point because Brunel is so often accused of extravagance.

The comparison between the great wrought iron tubes of Stephenson's Britannia Bridge and the hull design of the average ship built before the Great Eastern is a very apt one. With little or no knowledge of the actual stresses involved, ship-builders played for safety, as they thought, by constructing massive hulls in which a great deal of the strength and weight was in the wrong place. Compared with a bridge, of course, the stresses in a ship's hull are more complex. There are racking and twisting stresses as she rolls, while when she passes through heavy seas her longitudinal members are in tension one moment and in compression the next as she tends to hog or to sag. To these problems of marine engineering Brunel brought the same entirely fresh approach. He rejected the precedents to which ship-builders clung and worked the problems out afresh from first principles with results which were even more sensational than those he achieved in the railway world.

Brunel realised that the average ship's hull of that day, for all its appearance of strength, was fundamentally weak because that strength was in the wrong place. Ship-builders relied upon a massive system of transverse framing to give them this strength whereas in the vital longitudinal plane their hulls were weak. This was the traditional method of timber ship building and when men first began building hulls of iron they carried on that tradition. The hull of the Great Western, the first of Brunel's three famous ships, was of timber, but Brunel insisted that she be given far greater longitudinal strength than was then usual. This was undoubtedly the secret of her great success. The largest steamer afloat when she was launched, she was the first steamer to ply regularly on the North Atlantic route between England and New York, making no less than 67 crossings in eight years. She was also the first ship to hold the Atlantic Blue Riband and her best crossings of 13 days westbound and 12 days 6 hours eastbound were never equalled in her lifetime. In fact she was well named for she was the marine equivalent of the Great Western broad gauge express trains. Just as the G.W.R. had to abandon the broad gauge, so the Great Western Steamship Company ultimately failed. But like the broad gauge express the Great Western steamship was a technical triumph which showed the way to others, as we can see when we find the name of Samuel Cunard on the sailing list of one of her early voyages.

With the Great Western Brunel exploded a cherished myth that ocean steam navigation was not possible because no ship could carry enough coal for so long a voyage. Bigger ships were no answer, it was believed, because if you doubled the size of a ship you had to double its power and therefore carry double the amount of coal. Even Marc Brunel believed this fallacy which is typical of the pioneer generation of engineers. But his son with his superior technical powers realised that whereas the carrying capacity of a ship's hull increases as the cube of its dimensions, its resistance to motion through water only increases as the square of those dimensions, so that large ships require proportionally less power to drive them.

Brunel's second ship was the Great Britain, the first screw steamer to cross the Atlantic. In her hull, which was of iron, Brunel carried his ideas of ship design further. 'The plating of her lowest deck was, in effect, a false bottom for between it and the bottom plates ran a series of longitudinal girders which gave the ship great strength fore and aft. This was the germ of the idea of that double-skinned cellular construction which Brunel used on the Great Eastern and which is now common practice.

The hull of the Great Britain proved practically indestructible. Early in her career she went aground in Dundrum Bay in Northern Ireland owing to a navigation error and survived a battering which would have broken up any other ship in the world at that time. After she had been refloated and repaired the ship was in service until 1886. After that she served as a storage hulk in the Falkland Islands until 1937 and her derelict hull can still be seen there in Sparrow Cove.

Like her predecessor, the Great Britain was the largest ship afloat when she was launched although she did not hold that distinction for long. The huge Great Eastern, on the other hand, 692ft. long and 118ft. beam over her paddle boxes, was not surpassed in size for over forty years. Brunel's object, which was defeated by the building of the Suez Canal and other events, was to build a ship which could carry enough coal to steam to Australia and back-or in other words round the world- without refuelling. The enormous hull, which was launched with infinite difficulty at Millwall, just a century ago, was undoubtedly Brunel's final masterpiece of design and a landmark in marine engineering history. But he again made the mistake of jumping too far ahead of his time. There was no dock in the world large enough for her, harbour facilities were inadequate and her crew found it difficult to handle so large a ship without any of the electrical and hydraulic systems of communication and remote control which science has now provided. But the biggest trouble of all was that although the ship was powered with by far the largest marine engines ever built at that time, in those days of low pressure steam and slow speed reciprocating engines, engine builders simply could not give Brunel enough horsepower to drive his huge hull at the sustained speed of 15 knots which he hoped for. At a working steam pressure of 25 lbs. the screw and paddle engines of the Great Eastern together indicated 10,000 h.p., which seemed fabulous at that time, but the next ship of comparable size to be built, the Oceanic of 1899, delivered 28,000 h.p. from her two sets of triple expansion engines working at 192 lbs. per square inch. So the Great Eastern was obviously underpowered and seldom bettered 14 knots. But her great virtue was that her combination of screw and paddle propulsion made her far more manoeuvrable than any large ship ever built, a fact which helps to account for her success as a cable layer. The leviathan, as she was often called, was dogged by misfortune right from her conception and she caused Brunel continuous anxiety and overwork which undoubtedly led to his final illness and premature death. It was tragic that he did not live to see his great ship lay the first successful trans-Atlantic cable, an achievement which would have rewarded him for all his efforts.

Having dealt with a few of the technical high-lights of Brunel's career I want to say a little more about the man himself and the way he worked. One thing that strikes one immediately about him is his insistence throughout his life upon his absolute personal responsibility for any work which he undertook. He was often asked to act as a consulting engineer but always refused. In one such letter of refusal he summed up his attitude in these words: "The term 'Consulting Engineer' is a very vague one and in practice has been too much used to mean a man who for a consideration sells his name but nothing more. Now I never connect myself with an engineering work except as the Directing Engineer who, under the Directors, has the sole responsibility and control of the engineering and is therefore 'The Engineer.' In a railway, the only works to be constructed are engineering works, and there can really be only one engineer."

Certainly there was only one engineer of the Great Western Railway - no one connected with the Company from the directors down to the navvies was left in any doubt on that score. In these days of committees, consultants and specialist sub-contractors it may seem almost incredible that a young man of thirty should have absolute responsibility for every detail of the building of a railway from London to Bristol, yet so it was. When the directors dared to criticise one of his assistant engineers they received a sharp rap on the knuckles: "I really do not know why a gentlemanly and industrious young man should be subject to have his trifling actions remarked upon any more than I myself, unless the observer gave him credit for a much more gentle temper than I possess; because I confess, if any man had taken upon himself to remark upon my having gone to the pantomime, which I always do at Christmas, no respect for Directors or any other officer would have restrained me. I will do my best to keep my team in order; but I cannot do it if the master sits by me, and amuses himself by touching them up with the whip."

Brunel considered it part of his responsibility to defend his staff in this way, but woe betide them if they let him down or were guilty of shoddy work; this was the kind of rocket they would get. "Plain gentlemanly language seems to have no effect upon you. I must try stronger language and stronger measures. You are a cursed, lazy, inattentive, apathetic vagabond, and if you continue to neglect my instructions and to show such infernal laziness, I shall send you about your business. I have frequently told you, amongst other absurd, untidy habits, that that of making drawings on the backs of others was inconvenient; by your cursed neglect of that you have again wasted more of my time than your whole life is worth, in looking for the altered drawings you were to make of the station - they won't do."

Another characteristic of Brunel was his hatred of bureaucracy and his mistrust of any rules and orders which increased the power of government over the individual and so restricted that creative freedom which he prized so highly. Here is one example of this attitude. In 1848 there was set up a Royal Commission on the Application of Iron to Railway Structures. This Commission sought Brunel's views, but instead of the discourse on bridge design which they expected they received this answer: "It is to be presumed that the Commission will lay down, or at least suggest, 'rules' and 'conditions' to be observed in the construction of bridges, or, in other words, embarrass and shackle the progress of improvement to-morrow by recording and registering as law the prejudices or errors of to-day. No man, however bold or however high he may stand in his profession can resist the benumbing effect of rules laid down by authority. Devoted as I am to my profession, I see with fear and regret this tendency to legislate and to rule." One can only wonder what Brunel would have done in our regulation-ridden society. This attitude was, of course, similar to his reaction to the precedents established by Stephenson and Telford.

As to the principle which guided Brunel in his work, he explained this very forcefully in a letter he once wrote to one of his colleagues who had acknowledged defeat on a certain job: He wrote: "You have failed, I think, from that which causes nine-tenths of all failures in this world, from not doing quite enough. I would only impress upon you one principle of action which I have always found very successful, which is to stick obstinately to one plan (until I believe it wrong) and to devote all my scheming to that one plan and, on the same principle, to stick to one method and push that to the utmost limits before I allow myself to wander into others; in fact, to use a simile, to stick to the one point of attack, however defended, and if the force first brought up is not sufficient, to bring ten times as much; but never to try back upon another in the hope of finding it easier." It is significant that this letter goaded his defeatist colleague into trying again and with success.

I think these few extracts from Brunel's own writings which I have quoted should tell you more about his forceful personality and his professional philosophy than any word portrait I could paint. But I do want to stress again one other characteristic - his extraordinary versatility, because I think it illustrates the central problem of technical education to-day. Brunel was at once an architect, a civil engineer, a mechanical engineer and a naval architect, indeed there was scarcely any department of engineering or scientific knowledge at that time in which he was not perfectly at home. For instance, to take only two examples, he was an expert on ballistics who designed and had made for him by Westley Richards a rifle with an octagonal rifled barrel four years before Joseph Whitworth took out the famous patent which started a great armament industry. And he designed for his Great Eastern a device for taking observations which he called "a whirling contrivance" but which was really the crude parent of our gyro compass. In addition to all this he was an accomplished artist in watercolour and, in private life, a great lover of music and the theatre.

It was only in Brunel's lifetime that the professions of mechanical and civil engineer became distinct with the foundation of the Institution of Mechanical Engineers. This marked the beginning of a process of division and sub-division, of ever increasing specialisation which has continued down to our own day. The fact was, of course, that the accumulation of technical and scientific knowledge was so rapid and so great that specialisation of this kind was inevitable. The sum of knowledge soon became too vast for any one intellect however brilliant to contain and the phase of our industrial revolution when men like Brunel could range so freely over the whole field was very soon over. It could be said to have ended with the deaths of the three great engineers, Brunel, Robert Stephenson and Locke in 1859. All three died prematurely within a few months of each other. The effort to maintain their inclusive mastery was really too great and they worked themselves to death.

Materially, the process of specialisation has yielded astounding technical results since Brunel's day as we all know. Spiritually, however, there are grave dangers inherent in it and the further it is pursued the greater do these dangers become. Let me try to explain what I mean by this. Brunel was not only a great engineer but a great man; indeed one could say that he was a great engineer because he was a great man and it was his imaginative power and his wide ranging, liberal intellect which made him great. By contrast, we have reached a stage now where many specialised departments of scientific knowledge have become so complex that their mastery by the student demands the utmost concentration. There is therefore a grave risk that in the effort to acquire mastery in the particular narrow field he has chosen to pursue, his wider, more liberal education in the humanities and in the arts will be grossly neglected simply because there is no room for it. If this happens he may become a great expert in his chosen field but he can never become a great man. Science is a wonderful thing, but science alone is not synonymous with civilization - it is only a part of it and a man who is only educated to command a small part of that part is not a whole man and is not civilised. To put it quite bluntly, in the race for scientific supremacy which now seems to be going on between the nations it would be fatally easy to produce a generation of scientific barbarians. That would be fatal and catastrophic in its results.

I think our greatest strength lies in the fact that here in this country, I believe, we recognise this danger and this great educational problem more clearly than anyone else. I was delighted to read - as I am sure Brunel would have been - that in the educational aims of this new College this problem is recognised. That you intend to integrate theory with practice as closely as possible is admirable. That you aim to liberalise the curricula, not merely by introducing additional subjects but by recognising that the subjects of science and engineering can be the means to a liberal education if wisely and properly used - this is even more admirable. I am sure Brunel would be proud to know that a College with such enlightened aims as these had been named after him.

I was also very pleased to read that in the pursuit of these aims the study of scientific and engineering history is to be included. We can all learn a great deal from the past and a study of the achievements of our predecessors can give us a sense of perspective, of continuity and tradition. It can also teach us humility and this is even more valuable. When I was starting my own engineering career an old engineer said to me: "The older you grow the more you will realise how little you know." I have never forgotten that and in my own experience I have proved its truth over and over again. Just because we possess knowledge and command powers which were unknown to men of Brunel's day we tend to assume that in some way we are innately superior to them. This, of course, is false pride. Knowledge and power alone do not make us larger and better men. We often wrestle with problems which our forefathers have confronted and solved years ago simply because we have not the wisdom and the humility to learn from them. This can happen even in purely practical matters as I was reminded only a few months ago in a conversation I had with a very eminent civil engineer. He described to me in detail how he had evolved a method of side-launching the pier units for the famous Mulberry Harbour. Without knowing it, he had set himself to tackle the identical problem which Brunel had confronted when he decided to side-launch the far heavier Great Eastern nearly a hundred years before and the two solutions were very similar. The same engineer then went on to describe an ingenious method he evolved for dismantling the suspension chains of the old Chelsea bridge when his firm undertook its replacement by the present bridge. I think he was rather disgruntled when I pointed out that over a hundred years before Thomas Telford had used an identical method for assembling the chains of his Conway suspension bridge. I added that it was obviously a case of great minds thinking alike, but I don't believe this really consoled him.

The moral of this is that at all levels, from the philosophical down to the severely practical, the value of the study of scientific and technical history cannot be over-estimated. Believing this as I do, I hope I won't be thought impertinent if I end this lecture with a suggestion. It is that these annual Brunel Lectures should continue to be devoted to some aspect of scientific, technical or engineering history. I cannot think of any way in which the memory of this great engineer could be more fittingly perpetuated. I am privileged in being a member of the Newcomen Society which exists for the study of the history of engineering and technology. I am confident that this Society, which includes so many eminent engineers and scientists, would gladly provide you with future speakers for this series which I have been so deeply honoured to inaugurate.