The Lunar Society
4th Annual Lecture
Engineering the Future
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20 March 2007
Matthew Boulton College

I am honoured to be here tonight and address such an august institution who can name Boulton, Watt, Priestly, Wedgwood and Darwin amongst its former members.

I also note with interest the Lunar Society derives its name from the original practice – in the absence of sufficient street lighting – of scheduling meetings at the time of the full moon. I note with equal interest – and some-what concern – the traditional link in past generations between madness and lunar phases.

But then I am sure there is many an engineer who has suffered the insult of being called a lunatic!

Engineering the future.

As many of you would agree, any discourse on this subject could take up not just the time allocated to me, but the rest of the night. To begin with, however, I think it is useful to under-stand what we mean by the word engineer and the act of engineering.

My little Oxford thesaurus was disappointing. Noun: mechanic/technician. Verb: construct, devise. My thicker Collins dictionary was somewhat kinder. Noun: the originator or manager of a system. Verb: the application of scientific principles to the design, construction and maintenance of engines, bridges, roads etc.

Churchill once described an optimist as being someone who sees opportunity in risk, a pessimist as one who sees risk in opportunity. Successful engineers must be optimists. So what are the opportunities and challenges for the engineers of tomorrow to solve in a world increasingly risk averse?

The Stern Report must be top of the list.

A quick reminder of his key messages. In 50 years if no changes are made to CO_2 emissions, average temperatures will increase by 5°C. That does not sound a lot does it? But remember, the last Ice Age resulted from an average drop of 5°C.

The result, rising sea levels could leave 200 million people permanently displaced, crop yields will decline - particularly in Africa - and up to 40% of species could face extinction.

Tellingly, in the first decade of the 20th century, St. Mark's Square in Venice flooded fewer than ten times per year. By the 1980s, flooding was occurring 40 times per year. Since September 2000, however, over 60 flood events per year have been recorded.

The flood of November 2000 alone left 93% of the city under water. Engineers are now installing 39 marine sluice gates across the lagoons at a cost of €3 billion.

Stern says that if we are to contain these sort of impacts, then we must invest 1% of GDP per year in climate control now, or we will have to spend several times that in 20 years or it may well be too late or the actions will have to be too drastic. As for the action now, the lead must be taken by the developed nations.

I don't buy the argument which says that we risk becoming uncompetitive.

If we are, it will be in sectors where we are likely to be uncompetitive whatever we do, but by leading, we will generate new technologies and new products which will grow not shrink our economies. Think what would have happened had the Luddites succeeded in the 18th Century.

Incidentally, I read an interesting argument in a letter to the F.T. recently which suggested the Luddites might well have succeeded if, instead of trying to wreck the machines, they had organised the withholding of labour!

However, in order to have an understanding of what we might expect from engineers in the future in addressing climate change, I think it is important if we first delve back and understand what the engineers of the past have created and provided for their society.

But, how far back should we go? Who were the first engineers?

Engineering has created our world today. It has influenced our lives since the Stone Age and evolved through the Iron and Bronze Ages, Greeks, Romans, Renaissance, Industrial Revolution and into the modern era of space travel and digital technology.

At a recent meeting of the great and the good of the engineering world, the phrase 'rematerialise' was used in the context that American children, when asked where electricity came from, said 'out of the wall' – so clearly a challenge is to put back into clear shape and objective understanding the real nature, and form of, in this case electricity, and of engineering in general.

So how can we materialise engineering? Wherever I start, someone will claim it could have been earlier - rather like the time of the next train - but I am going to start with the Stone Age. Here the Little Oxford definition to construct and devise works quite well.

The knowledge gained by experiment and experience that certain stones were harder than others, some could be made sharp, some were brittle, some like volcanic were light, or like granite – heavy, that the use of water or sand would make some smooth, combined to create useful tools, weapons, and protective walls.

Later, Bronze and Iron Age man utilised a more scientific form of understanding in the heating and working of natural materials to create similar artifacts, but in addition vessels, clothing, jewellery and strong wheels - the earliest wheels by the way, date back to 5,000 BC Mesopotamia.

The earliest machines or engines of war, battering ram and towers, required an under-standing of the relative strengths of materials and how they could be mobilised into powerful siege engines.

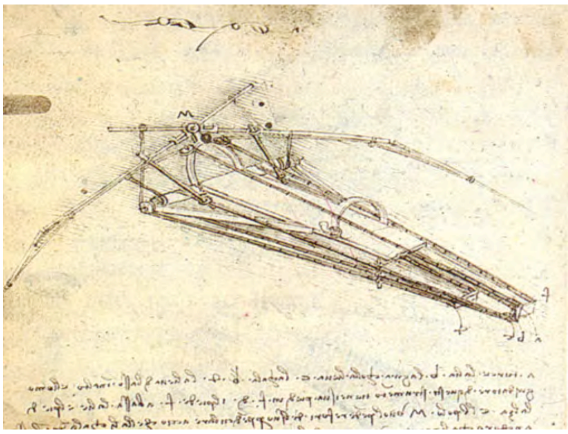
My next stop is ancient Greece with their elegant simple structural engineering solutions for buildings such as the Parthenon, which for the first time addressed the question of the relationship between engineering and architecture, and their ships using the simple power of the lever and action reaction between oar and water, aided by the wind, with the ships again utilising metal and timber as battering rams.

Our first mechanical engineer is arguably Archimedes, born in 287BC Sicily, which was then a part of Greece. If you have spare time in Rome – rather ironic as Archimedes was a Greek killed by a Roman soldier in the Second Punic War - I recommend a small Museum just off the Piazza del Popolo, dedicated to Archimedes with working models of his inventions nearly all based on the interaction of screws, cogs, cams and levers to create water lifts, heavy hammers, bird wing devices, and even the first bicycle made of wood.

On to the Romans and the first engineered roads designed to move their legions quickly and reliably, coupled with their understanding of the use of water for domestic heating systems – at least for the generals' villas if not for the soldier's barracks - and the first use of lime and water to create concrete.

I'll skip the medieval ages - although the English Long Bow was a simple example of the effective engineering of natural materials – and move on to the Renaissance and Leonardo da Vinci, scientist, mathematician, anatomist, painter, sculptor, architect, musician, writer.

But it was as an engineer that Leonardo conceived ideas centuries ahead of his time, conceptually inventing a helicopter, a tank, the use of concentrated solar power, a calculator, a rudimentary theory of plate tectonics, the double hull, and many others.



Although relatively few of his designs were constructed or were feasible during his lifetime, he nevertheless greatly advanced the state of knowledge in the field of civil engineering long before anyone had heard of Dan Brown!

In the meantime, across Europe and in Britain, we have soaring cathedrals taking the understanding of structural engineering to new heights and creating an architectural legacy we still enjoy today.

On a smaller but more important scale, we had the development of the printing press and the spread of knowledge.

In the late 18th Century we see the quickening of pace in the knowledge, understanding and implementation of engineering, particularly in Civil and Mechanical Engineering.

The two combine most graphically in the rail-way. Having, in recent years, been required to increase my knowledge of this phenomenon, I never cease to be staggered.

Staggered by the sheer vision and inventiveness of the Telfords, the Stephensons, the Brunels, father and son. Staggered by the investors' clamour, and in some cases lack of appreciation of the risks. The railway was Britain at its boldest.

The combination of wealth and engineering imagination created more change in people's lives in 50 years than in the previous 5,000 years. Engineering created the Industrial Revolution, the fundamental societal shift from the land to the factory, an explosion in inter-national trade on the back of Empire.

Of course such change is not all blessings, the growth of the industrial city, extensive use of child labour - no doubt always the case on the land - but given a new brutality in the sweat shops and coal mines.

The pollution of the Thames from population growth and industrial waste resulted in cholera for the poor and the eventual indignation of MPs in Westminster - who had to endure the Great Stink - and led to the work of Bazalgette

THE "SILENT HIGHWAY"-MAN

providing the embankment, drainage and sewage systems of London, described by the Observer of 1861 as *the most wonderful and extensive work of modern times*, and which we still use little changed today.

It was not only engineering that was making rapid strides. Science and medicine also made new discoveries and fermented new concepts.

From Faraday and electromagnetic induction, to Sir Henry Bessemer who discovered how to convert pig iron into high grade steel and whose ingenuity stretched from inventing devices to combat *mal de mer* to the production of crushed velvet wallpaper for which a generation of Chinese restaurant owners are grateful!

Victorian inventiveness was celebrated at the Great Exhibition of 1851. Perhaps we should not be surprised that the Government was not supportive of the idea despite - or perhaps because - the French had already created a tradition of exhibitions. In Britain, it was here in Birmingham that the first building was erected solely for the exhibition of manufactured goods in 1849. However, encouraged by the Prince Consort, a self-financing, multi-nation exhibition was held in Hyde Park. From its Paxton design to completed building in only nine months, it had a simple, repetitive iron and glass structure.

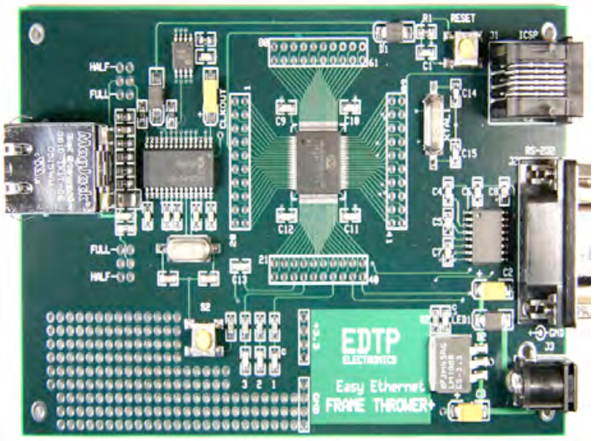
The pessimists feared it would fall down due to the vibration from the thousands of visitors. So the Army was called in to troop up and down. The maximum girder movement was one-quarter-of-an-inch and the following 6M visitors in six months caused no damage. What they did was marvel at the exhibits ranging from the sublime to the ridiculous from around the world including the USA, Russia and China. The exhibition even made a profit which bought the land for the V&A, Natural History and Science Museums.

The Exhibition must have fired the imagination and enthusiasm of many young visitors to become engineers. Indeed, the catalogue for the exhibition said of them: *they are the men of tubes and tunnels, they level hills and change the course of rivers, creating structures with a clarity and ease that shame the Pharoahs*.

Let me complete my retrospective with a reminder of engineering development in the 20th century. Central to our transport and energy needs is oil. It has been shovelled up for centuries from surface deposits and used for cooking, lighting, painting or throwing over castle walls at invaders. Incidentally, the first commercial oil well, drilled by James Miller Williams in Ontario, Canada, was sunk in 1858.

Oil, the basis of petroleum for the internal combustion engine and the motor car – after the railway the next great liberator of mans desire to roam and hence, in part, destroyer of the integrated, local, self-supportive community. The aeroplane, a combination of sailing in the air and the combustion engine reducing anywhere in the world from weeks and months to just a few hours journey.

Electrical power systems, the basis of all modern life, the miniaturisation of manufacturing processes enabling the hardware to support mathematicians' software and hence computer power, the equal miniaturisation and materials technology to provide surgical equipment which allows the most amazing operations and life extension.



The creation of new materials, stronger, lighter, durable - perhaps too durable. The stuff of modern life is all the work of engineers in the various disciplines of civil, electrical, mechanical, chemical, marine and aeronautical engineering.

I defy you to think of any aspect of modern life which at some point does not involve engineering for its creation. Even our escape back to nature relies on engineers to get us there and our survival once there, whether on our ice pack, in our rain forest or 50 fathoms down.

Is it that we have so much and take it for granted that we are still somewhat dismissive of the mechanical skills of the creators?

Today's politics and celebrity is news and it is argued engineers do not influence politics enough. Ironically, it is the case that engineers are often the creators, albeit unknowingly, of the issues the politicians subsequently grapple with. For instance, have modern communication systems and ease of transport led to the breakdown of family units and a rise in crime, or of course climate change? Or in medicine, has the success of modern techniques led to an increase in demand and thus longer waiting lists? And then the engineer is called upon to resolve the political problems with, for example, health service computers - not that on present reporting that seems destined for glory - or CCTV for crime surveillance?

What is undoubtedly clear is that the future, good, bad or indifferent, will be strongly influenced by the work of engineers. I have a simple view that what we can imagine, sooner or later we will achieve. Recent examples where science and engineering have delivered for the imagination of the leaders were the missiles and planes of the Second World War, or the ability of America in the space of just 10 years feverish activity to put a man on the moon.

But back to Stern and the challenge of climate change. The future is probably electric, so how to generate electricity and how to limit demand for it are key questions. On the question of electricity supply, the debate so far would suggest you cannot please everyone.

Nuclear provides contained, very low cost, generation – the question mark is over the treatment of used fuel and the cost of decommissioning. France obtains 90% of its electricity from nuclear, the UK 20% and falling. Today, it is the only option for providing quick, large scale, cheap electricity – the challenge for it to be more politically acceptable is one of safe and efficient treatment and storage. As engineers we must address peoples fear, develop technical solutions and be prepared to express our views in public.

It is attractive to believe that natural sources, wind, sun and the tides, can provide alternatives. They can, but so far in small volumes and also with significant environmental impacts, witness the debates around the wind farms and barrage containment, the visual effects on areas of outstanding natural beauty, or siltation on bird and marine life.

Locating wind farms offshore is an expensive option whilst wave generation requires more commitment to investment and research.

There are other solutions such as the use of the natural heat or the Earth's core to superheat water. One such scheme, however, has recently been stopped owing to the fear of earthquakes being instigated.

The reality is that going forward we will need to use all of these options and minimise the undesirable consequences.

For engineers, the task will be in each case to maximise efficiency of the process, reduce the capital costs and participate in the democratic process with an open mind. There is no benefit in being technically correct if you cannot win over public opinion.

25% of CO_2 emissions are as a consequence of our desire to travel. Stern points out that stopping one year's worldwide deforestation would balance one year's transport emissions. To stop deforestation is an issue of international politics and business. It may be appealing, but it will take time and we cannot wait. We must address our current transport modes and their emissions now.

In part, our search for new solutions is driven not just by a desire to reduce emissions but by a belief that our stock of natural hydrocarbons will expire.

We should not be too pessimistic here. In the last 50 years, each time such a forecast has been made, petroleum engineers have devised new ways to extract more from existing wells, or have devised new ways to drill in deeper and deeper waters. We know more fields lie under frozen parts of the world where it has only been the cost which has so far prevented exploitation. There can be no doubt that there are many exciting challenges ahead for engineers to harvest these fields whilst doing so in a way which minimises the local environmental impact.

Bio fuels are seen by many as a quick win to reducing emissions. But there is a *but*! They are less efficient and produce more sulphur dioxide. Recent tests on rail locomotives have demonstrated less power and fewer miles per gallon. So more work to be done.

I am confident industry can continue to reduce emissions by lowering vehicle weights, improving engine efficiency, continuing to develop hybrid engines and by the use of alternative fuels. However, it is an area where political impetus is needed through statutory emission targets to provide a certainty for further investment by industry.

Given the scale of investment needed to develop new technologies in all areas of electricity and transport supply, there will have to be clear and long term political decisions. We must hope this is not too much to ask.

As engineers, we must work together to pro-vide a consensus of advice to assist politicians. Again, hopefully not too much to ask, and a task which the Royal Academy of Engineering is addressing under the Chairmanship of Lord Browne.

Of course, our need to travel can be reduced by improved communication. Here engineers have already generated enormous changes through satellites and fibre optics, whilst the development of nano technology, or the reduction of size by ten to the power of nine or one billionth, is enabling computing and storage of information capacity to be contained into smaller and smaller devices.

So far we have used the benefits of technology and communication to travel more and still keep in touch across thousands of miles. Is that the future? Asia's billions will want to travel in the future, and should not be denied the opportunity. Or is the future one of virtual reality experiences without having to leave our homebase? Are we getting closer to variants of the Orwellian society and its feely movies?

But our future must also be one of controlling and managing the supply side. Road pricing when we are charged variable rates according to when and where we drive. After all, we accept the equivalent in our homes with our electricity or gas consumption.

The key to road pricing philosophically is it requires people to make choices. The politician can influence those choices by setting the charges – hopefully the recent Number 10 petition will not cause a lasting loss of political bottle. The engineer can without doubt deliver the technology, again, how quickly will depend on clear political policy.

On the railway we are faced with having to build extra capacity through miles of track and numbers of trains for a couple of hours in the morning and the same in the evening when the majority of people travel to and from work.

Commuters represent two-thirds of all rail use. Can we influence those behaviours, so that the existing demand is spread more evenly? Again, it is probably a matter of smart card charging, which technically can be done.

We are currently modifying trains to regenerate electricity when braking so reducing overall con-sumption, but for trains to be really environmentally and economically effective, they need to be full and utilised regularly throughout the day. Journeys up to a thousand miles currently made by plane can be replaced by high-speed rail.

But today's engineer is not only required to im-prove the environment, he also has other challenges - in medicine and surgery, in helping the poorest nations with the basics of healthy life such as clean water and sewage control, or in seeking new ways to utilise the two-thirds of the world covered in water.

Farming the sea not just for fish, but for new food crops will require the skills of scientists, biologists and engineers.

In medicine the development of new materials and their application to prosthetics, micro-surgery, the development of artificial intelligence prompted by the body's signals are sometimes beyond comprehension.

But engineers are involved in every new develop-ment and opportunity for a better quality of life for the disabled. Sometimes these advances are ahead of what we can comfortably absorb as being of the natural or moral order. However, in the same way as our scientific and engineering skills develop, so we must be ready to question and challenge our traditional and moral opinions.

A particular challenge for agriculturalists, biologists and engineers, one which has been since recorded time, is how to feed the world.

Whilst poor communities can be helped to be self-sustaining, nature has an ability to wipe out their efforts mercilessly.

The reality is that the large scale growth of crops using every modern technique available will be the answer. You cannot have half the world living an industrialised life and require the other half to be 100 years behind because it's good for them and because in a superior way we think the 'good life' is all they need.

So genetic crops will not go away. Of course there will be some mistakes. John Le Carre's novel *The Constant Gardener* questioned the ethics of, in this case, global companies' development of new drugs, but you do have to be prepared to question and value the risk of some harm to a few for the good of the majority.

Yes, these are ethical issues, and engineers cannot dodge them. Ethics are not the territory of philosophers, the green parties and moralists alone.

One thing is certain – man will never stand still. He will never be content with the status quo. He has the ability to destroy himself, but equally has the ability to continue into a new and different world. What is certain is it will be different, but will it be better? Some will say no because some personal freedoms will be lost, but many of those freedoms have been selfish and served a small proportion of the world's population.

So if we want an optimistic future for the majority of the world then we must use all our skills be they political, philosophical, scientific or technological.

The engineer has a central role to play, he can create, he can lead, he can respond. In the words of John F Kennedy:

"The problems of the world cannot possibly be solved by sceptics or cynics whose horizons are limited by the obvious realities. We need men who can dream of things that never were."

Without the engineer there are no choices, no opportunities; he is the provider of our physical world in every respect.

He has always been the provider of excitement, of awe. Who could not look in awe at the structures of Greek and Rome? Who could not be in awe of the machines, terrible as they were, of war? Who could not be in awe of the triumphs of the Industrial Revolution and the changes and opportunities it created? And more latterly be moved by man's achievements in space, of Concorde, of the advances in medicine, in communications, the power of the computer and the web?

My branch of engineering, Civil Engineering, has been described as harnessing the forces of nature for the use and benefit of mankind.

The Aswan or Hoover Dams would be classic examples, controlling mighty rivers to reduce flooding, develop agriculture, and provide hydro-electric power. Today, in order to be politically correct, we introduce additional phrases such as 'in a sustainable manner'.

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Mankind's long term benefit has to be one which sustains our world as one in which we can all comfortably survive and prosper and of course, sooner or later, inevitably reach out to new planets, so far unexplored.

Given the scale of the challenges and opportunities ahead, will there be sufficient courage and intellect to meet demand?

If we look at this challenge on a global scale the answer is most probably yes. The universities of India and China are producing large numbers of graduates, many fluent in English, who do not see their futures solely at home, and they look to the West for their early careers. Our own universities see opportunities for their own development in working with the Asian universities.

In the UK, our ability to do so will depend on the continued nurturing of our engineering skills. We must ensure we provide society with those skills.

To do so will require changes in our education systems and processes at every stage. Primary education must improve. At Network Rail we are providing 250 places a year for apprentice engineers.

But first and foremost it requires engineers to lead, to excite, to be political, to ensure the rest of society the choices, the possibilities of a future based on optimism, humanism, and freedom from fear.

I hope that I have been able to make a small contribution this evening.

Thank you.

John Armitt

John Armitt is a Fellow of both the Royal Academy of Engineering and of the Institute of Civil Engineering.

Born in North London in February 1946, he is a lifelong Arsenal supporter. He has a son and a daughter, and two grandchildren.

He studied Civil Engineering at Portsmouth College of Technology and started a long career with John Laing Construction in 1966. During the next 27 years he worked on major projects in the UK and around the world, including: power stations, oil rigs, petrol-chemical plants, airports, roads, bridges and hospitals

In 1993 he was appointed Chief Executive of Union Railways, the company responsible for the Channel Tunnel Rail Link. In the following four years the route was agreed, an Act of Parliament processed and construction of the high speed link begun. In 1997 he was awarded a CBE for his contribution to the rail industry

In April 1997 he rejoined the construction industry as Chief Executive of Costain Group plc.

In December 2001 John was appointed Chief Executive of Railtrack plc (then in Railway Administration) and subsequently in October 2002 of its successor Network Rail; the post he held when he gave this Lunar Society Annual Lecture. He will step down from this position in July 2007.

On 1 April 2007, he became Chairman of the EPRSC for a four-year period. He will also become Chairman of the Olympic Delivery Authority on 1 September 2007.