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"Landmarks of Engineering History"

by Andrew H. Wilson

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Abstract

Engineering history is a continuum of achievement in invention, innovation, design, manufacturing and construction extending back many millennia. But from time to time, certain periods have appeared (to me at least) to have been more significant, productive and redolent of change than others. This paper identifies six such periods, or concentrations, ranging from the Seven Wonders of the Ancient World to the 1950s, and describes some of the achievements of each. It an expanded version of the presentation given by the author in the Almonte (Ontario) Lecture Series in April 2015.

About the Series

Principally, the Cedargrove Series is intended to preserve some of the research, writings and oral presentations that the author has completed over the past half-century or so, but has not yet published. It is, therefore, a modern-day variant of the privately published books and pamphlets written by his forebears, such as his paternal grandfather and grandmother and his grandfather's brother John.

About the Author

He is a graduate in mechanical engineering and the liberal arts and has held technical, administrative, research and management positions in industry in the United Kingdom and the public service of Canada, from which he retired almost 30 years ago.

Over the years, he has written and published on many subjects, from science policy and human resources associated with engineering to building economics, as well as engineering history, in which he became actively interested on his appointment to chair the first history committee of the Canadian Society for Mechanical Engineering in 1975. He has since done work in this field for CSME, the Engineering Institute of Canada and the Canadian Society of Senior Engineers. He has also served as president of CSME and EIC.

Introduction

The word 'landmarks' - as I propose to use it in this paper - may be defined as "concentrations of events or persons marking stages in the development of the history of engineering" and not simply buildings or other surviving artifacts from the past. With time, these concentrations have also become increasingly shorter.

I also propose to consider engineering to be, simply, "the use of energy, materials, machines and physical laws to enhance human capabilities." It is in practice an *activity* that is as old as civilization and began long before it was formally recognized as such or as a particular human skill practised in the military or civil contexts. Its practice has been, and still is, necessary for the survival of human beings. It can also be imaginative, inventive and innovative as well as useful. An *engineer*, therefore, is someone who gets things done.

In contrast, science (know-*why)* and technology (know-*how*) I consider to be *bodies of knowledge* from which engineering borrows freely and applies to the work it does. But engineering also applies knowledge from other sources, as well as from that most valuable source, experience.

As it has evolved into modern times, engineering has developed sub-activities, such as design, development, testing, construction, manufacture, operations, research and the provision of services. It has also been divided into disciplines and sub-disciplines, such as civil, mechanical, electrical, chemical, aeronautical, marine, structural, materials, electronic and computer engineering.

Augustus B. Kinzel, the founding president of the U.S. National Academy of Engineering, observed in an article that appeared in the June 1967 issue of the magazine *Science*:

> It is a long way from the original engineering act of the caveman - the rolling of a large rock into the entrance of his cave for a door - to the construction of the modern skyscraper. It is an equally long way from the first wheel and axle, which the caveman made by putting a stick into a hollow log, to today's laser. The last 6000 years have shown many major advances, but it is only very recently that the effect of engineering on our civilization and society has been a major, if not *the* major, factor. In those 6000 years that preceded the harnessing of steam,...engineering simply served society and had little impact on its evolution. Engineering started by serving government, then served the individualistic community, and now again it is serving government.

People 'engineered' before the activity was given a name. The earliest records of engineered products are of the tools, weapons and other artifacts used by people in their primitive struggles to survive, to hunt, to travel and to ward off enemies of both the human and animal kinds. These have included arrowheads made from stone, spears made from tree branches, and knives made from animal bones and primitive ores. The people themselves wore animal skins sewn together using needles, also made from bones. They travelled on land on foot or on the backs of domesticated animals, over water in dug-out and other canoe-type boats, and over snow on toboggans and sledges.

The date when Stone Age people first used fire to heat, cook, melt ores and do other chores is uncertain. What is certain is that the ability to control and use fire was the primary skill that made the engineering of a lot of the earliest artifacts and activities possible. It had a direct influence, for example, on the ability to make bread, bronze and bricks, as well as providing light and warmth.

Where people lived, and the climates they lived in, governed the kinds of engineering that were done during the Stone Age. We are also aware now that, during the Bronze and Iron Ages, the engineering in places like North and South America, China, India, Australia, the Middle East and the different parts of Europe developed essentially in local isolation. The boomerang, for example, was developed independently as a hunting weapon in Egypt, Eastern Europe and Australia. The availability of water was a major influence. The process of construction and the materials used were local in nature.

The growth and development of trade, based on transportation by domesticated animals, began to change that. Trade along the so-called Silk Road, for example, helped bring Chinese inventions and engineered developments to the attention of those in the Middle East and Eastern Europe, and vice-versa. Communication was usually by word of mouth, gesture and demonstration.

Opinions differ on the origin of the wheel. Perhaps it began life as a log - or a series of logs - being rolled along the ground and assisting with the transportation of heavy and bulky loads. We *do* know that the usefulness of wheels was increased when solid ones were replaced by those with rims, spokes and hubs. We also know that the engineering of axles and bearings was just as important, if not more so, than that of the original wheels.

Throughout history, wars have provided significant stimuli for invention and innovation in engineering. Indeed, the first formal recognition of engineering as a profession was in association with military works and weapons. However, in regard to the landmarks chosen for this paper, I have included the occasional reference to wars fought and weapons developed during them, but have identified no specific war as a stand-alone landmark.

The earliest group of landmarks I have chosen are the so-called Seven Wonders of the Ancient World. The second group is based on the Renaissance in Europe. The third, I call 'the Smeaton-to-Watt Years' – spanning the active lifetimes of two of the engineers who initiated the First Industrial Revolution, which was based on steam and iron.

As an aside, I should say that I believe there to have been, so far, not one but three Industrial Revolutions. The first, the Smeaton-Watt one, lasting from roughly 1750 to 1850, based on steam and iron, the second from 1850 to 1950, based on transportation, steel and electric power, and the third, beginning 1950, based on electronics and space travel, which is still continuing today.

The fourth landmark period coincides with the beginning of the Second Industrial Revolution and is sandwiched between two international exhibitions, the English one at the Crystal Palace in London in 1851 and the American one in Philadelphia in 1876. The fifth landmark straddles the end of the 19th and the beginning of the 20th centuries. The sixth is limited to the decade of the 1950s, and the beginning of the Third Industrial Revolution.

For those readers who are engineers or historians, my choice of landmarks may differ from the ones you might choose. But the simple process of making choices emphasises the fact that the history of engineering is replete with examples of such events and people.

The Seven Wonders of the Ancient World

The original list was apparently made by Greek scholars at the Museum of Alexandria. The important thing about this landmark is that it happened.

Historically, one of these Wonders was built 1800 years and more before the other six. The Great Pyramid of Giza, near Cairo, Egypt, was built around 2500 BC and was the tallest building in the world for a very long time. Although of typical pyramidic design, and the largest ever built, this one was notable for the precision of its siting and construction. It was 480 feet high and consisted of 2 million limestone blocks, weighing from 2½ to 15 tons.

The Pyramid of Giza

Although not included among the Seven Wonders, I should mention several other significant examples of engineering contemporary with the Giza pyramid:

- the sewer system built at Skara Brae in the Orkney Islands off Scotland's north coast;
- the temple complex built at the Ness of Brodgar, just a few miles from Skara Brae;
- the public drainage system built at Moenjodaro in the Indus Valley in what is now Pakistan;

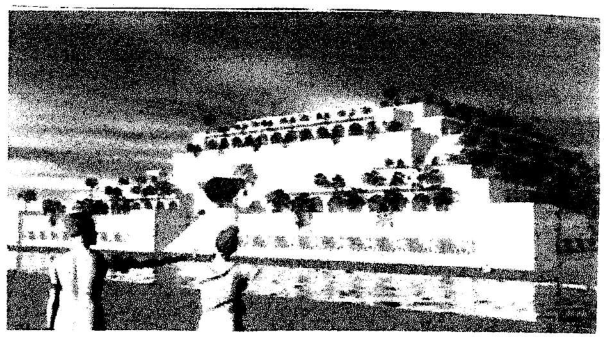
- the first circle of stones erected at Stonehenge;
- the rivets made of bronze that were used to join plates of the same metal;
- and the slow burning of hardwoods that turned them into charcoal and provided higher sustained heating for the production of metals and other uses.

The other six of the Seven Wonders date from the 7th to the 3rd centuries BC.

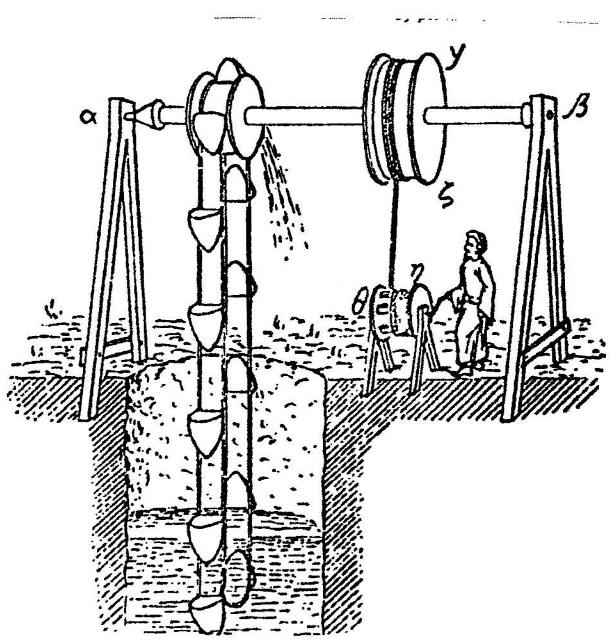
The Hanging Gardens of Babylon were built around 600 BC, and may not sound like an *engineering* achievement. They were in fact a series of artificial terraces and balconies, with plants *overhanging* rather than simply hanging, rising to 80 feet above the Euphrates River. Apart from the huge mud brick (with lead waterproofing) construction of the terraces, the notable engineering involved the mechanical systems bringing essential water up from the river. These consisted of manually-driven endless chains, with top and bottom wheels and attached buckets that dipped into the river at one end and deposited the water into pools at the top. The water could then be released into channels that carried it to the plants. These chains may also have been supplemented at the lower levels by the water-bucket-on-a-long-pole, or shaduf, developed originally centuries earlier in Egypt.

The Hanging Gardens, apparently, were destroyed by an earthquake around 200 BC.

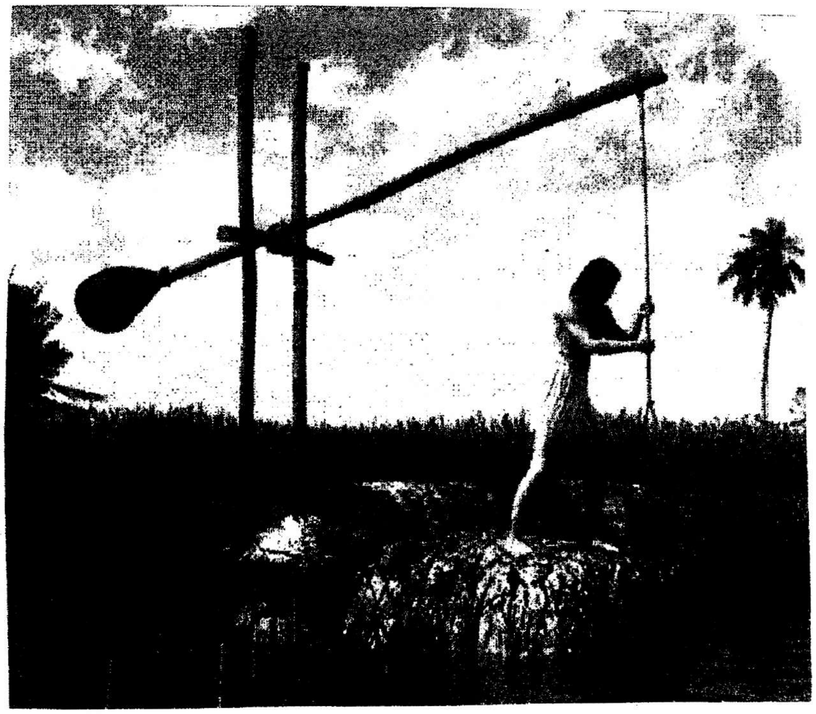
The Hanging Gardens of Babylon



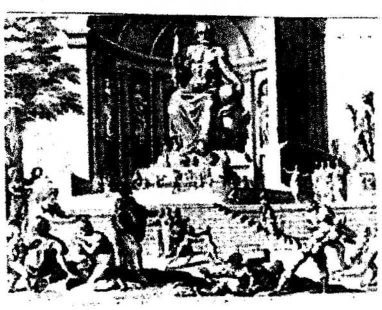
The bucket and chain



The shaduf



The statue of Zeus at Olympia, by Phidias, dated from around 400 BC and was of Zeus seated on a cedarwood throne, was 43 feet tall and was made of ivory plates and gold panels over a wooden framework. It was apparently destroyed sometime after 400 AD.

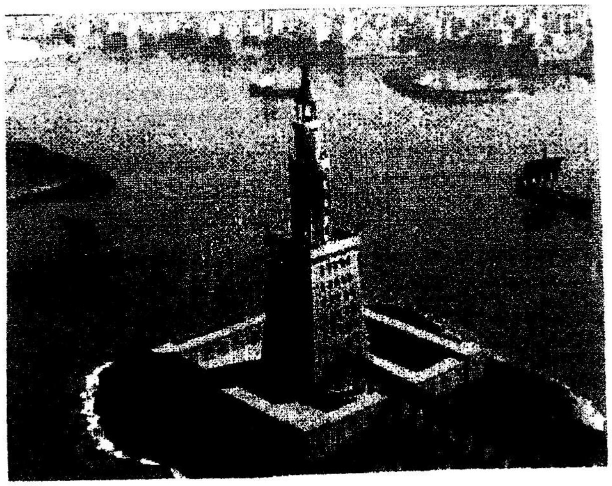


The statue of Zeus

The Colossus of Rhodes

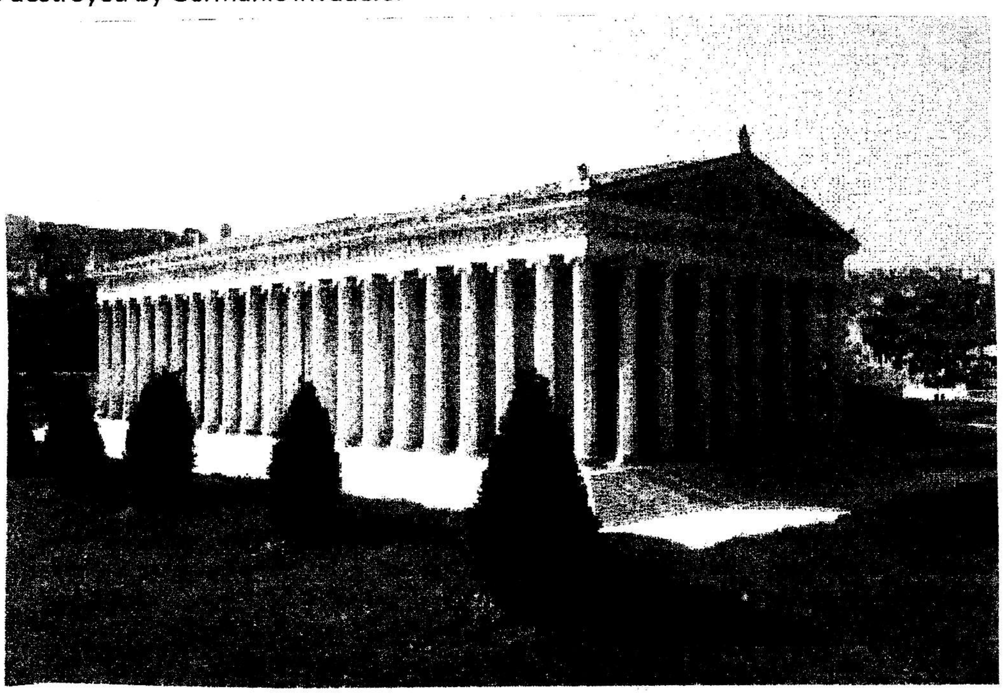
The statue of the god Helios - the Colossus of Rhodes - was 110 feet high and was the work of Chares of Lindos. It had an outer skin of bronze, with an iron and stone framework, and stood on a base of white marble. It was built around 300 BC but destroyed by an earthquake only 56 years later. It did not, apparently, straddle the entrance to the Mandraki harbour.

The Lighthouse of Alexandria, built on the Island of Pharos, was the first lighthouse in the world. Construction took 20 years and was begun in 290 BC. It was 450 feet tall, almost as high as the Pyramid of Giza, was built on three levels and topped by a statue of Poseidon. The beacon was a fire and the stairs inside allowed people to climb to the beacon chamber. The lighthouse was damaged by three earthquakes and abandoned as a ruin after the third, early in the 14th century AD.



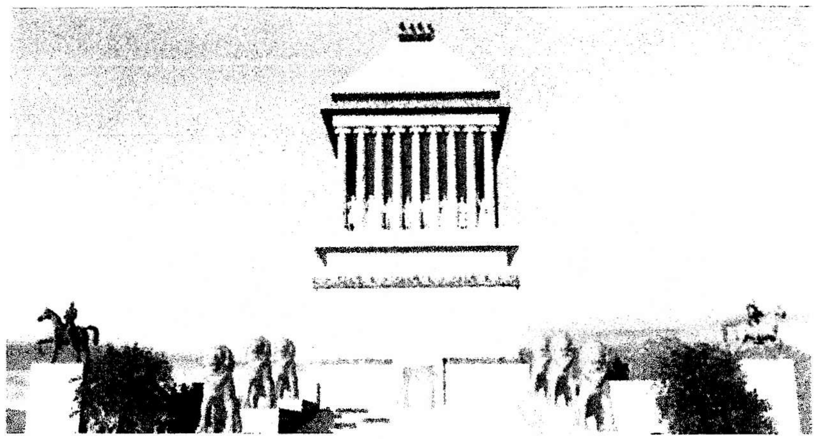
The Lighthouse of Alexandria

The Temple of Artemis, also known as the Temple of Diana, was located at Ephesus in Turkey. It was built at least twice, the first time around 550 BC, of marble with wooden roof beams and columns 40 feet high in double rows. This one was destroyed by arson around 400 BC. It was rebuilt around 100 years later, larger than the first, was 60 feet high, with 127 columns. This one survived for 600 years, until it was destroyed by Germanic invaders.



The Temple of Artemis

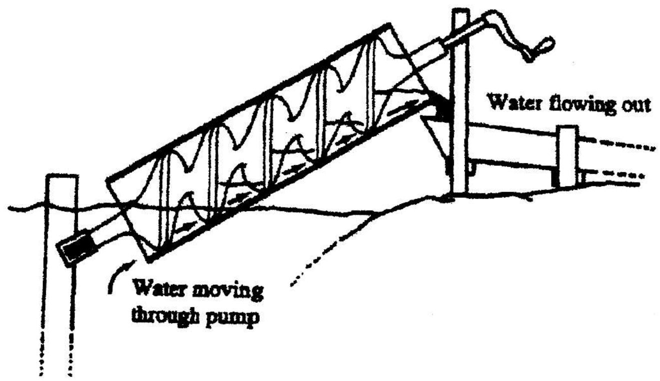
Finally, the Mausoleum of Halicarnassus, on the Mediterranean coast of Asia Minor, was built around 350 BC as a tomb for King Mausolos. It stood around 140 feet high and was made of white marble. It was damaged by earthquakes in the 13th century AD and finally destroyed by the Crusaders in 1522 AD.



The Mausoleum of Halicarnassus

Again, not included among the Seven Wonders of the Ancient World, I should again mention some engineering achievements during the centuries of the 'other six' Wonders, including:

- in the 7th century BC, the Chinese began building their Great Wall;
- In the 6th century BC, Eupalinus of Megara, a Greek, drove a 4000-foot tunnel through Mount Kastro on the Island of Samos - starting from both ends - to serve as a water supply aqueduct; it remained in use for 1000 years;
- The Romans developed the semi-circular stone arch as a structural component and, from the 4th century BC onwards, used it in their aqueducts and other buildings; they developed the syphon as a means for getting channelled water, that had descended into a valley, out of it; they also built 18,000 miles of roads across Europe, and discovered possolana (volcanic ash) hydraulic cement, that would harden under water;
- Philo of Byzantium developed the military catapult during the 3rd century BC;
- around the same time, Ctesibius developed a compressed air pump and improved the water clock;
- and Archimedes, famous for his 'Eureka' cry and his 'floating bodies' principle, invented a hand-operated screw pump for raising water between levels, built the first block-and-tackle pulley, and contributed new weaponry for the defence of his home city of Syracuse in Sicily.



The Archimedes Screw

As a second aside, I should note that, among the contributions of the Middle Ages to engineering achievement, were the building of huge, ornate churches, enormous fortresses and deadly weapons of war. The term 'master builder' was in common use in Europe to describe the engineer/architects who built the great buildings, and it was sometime during the 14th century that the term 'engineer' was applied in the military context.

The Renaissance

We jump around a millennium to the period from the 15th to the 17th centuries, to the Renaissance, largely a European phenomenon, with Italian beginnings, that followed the Hundred Years War and the Black Death, which had decimated the populations of that continent. Its importance as a landmark lies in being a fresh start, with a new base - an association with science and experiment.

The Renaissance included the Age of Discovery, when European explorers fanned out across the world in search of new countries and new sources of wealth, including such people as the Cabots, Vasco da Gamma, Pizzaro, Columbus, Vespucci, Magellan, Cartier and Champlain, who found during their travels engineered structures and devices developed by the non-European peoples they encountered. And it led to the so-called 'Age of Reason' of the 18th century.

But the Renaissance also continued warlike activities, both civil and between countries, as well as riots and revolutions. Even stronger fortifications and deadlier weapons were developed, including iron and brass cannon with bored barrels. The most spectacular European building erected during the Renaissance was perhaps St. Peter's Basilica in Rome - a century or so after Machu Picchu had been built by the Incas in the Andes Mountains of Peru.

A particular engineering-related Renaissance event that helped change the world more rapidly was the introduction of moveable-type printing in Europe (although the Chinese, Japanese and Koreans were already doing it) - usually attributed to Johann Gutenberg of Mainz, Germany, around 1440.

Gutenberg

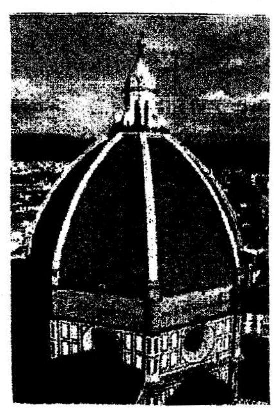
Leonardo da Vinci

The dominant name associated with the Renaissance and its engineering is that of Leonardo da Vinci - engineer, architect, inventor, scientist, sculptor and painter. Born in 1452 near Florence, Italy, his training as an artist carried over to his engineering drawings. He left behind an immense number of these drawings, as well as technical manuscripts - not always easy to read since he often used mirror-writing. Over the centuries, and right up until the present time, scholars have analysed Leonardo, his talents, his career, his ideas and his legacies. Perhaps most importantly, da Vinci left behind many *engineering* ideas, some of which were realized long after his death, in 1519, in France, at the age of 67.

Leonardo da Vinci was not alone. Others followed similar career paths and contributed to the renaissance landmark. Like da Vinci, most were dependent on patrons for support of their artistic and engineering endeavours.

Filippo Brunelleschi, for example, originally a goldsmith, also had an architectural and artistic background. He designed and built the cupola of the cathedral church of Santa Maria del Fiore in Florence, including the development of new methods for lifting materials upwards from the ground. He also designed fortifications, hydraulic and clockwork machinery and was granted an industrial patent for a barge with lifting gear to carry marble.

Brunelleschi

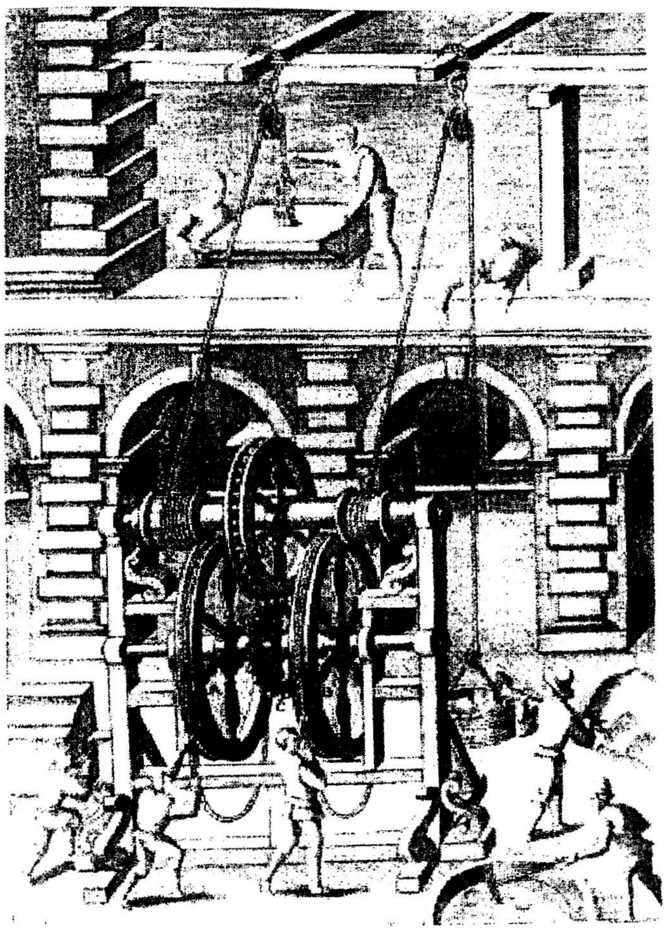


...and his dome

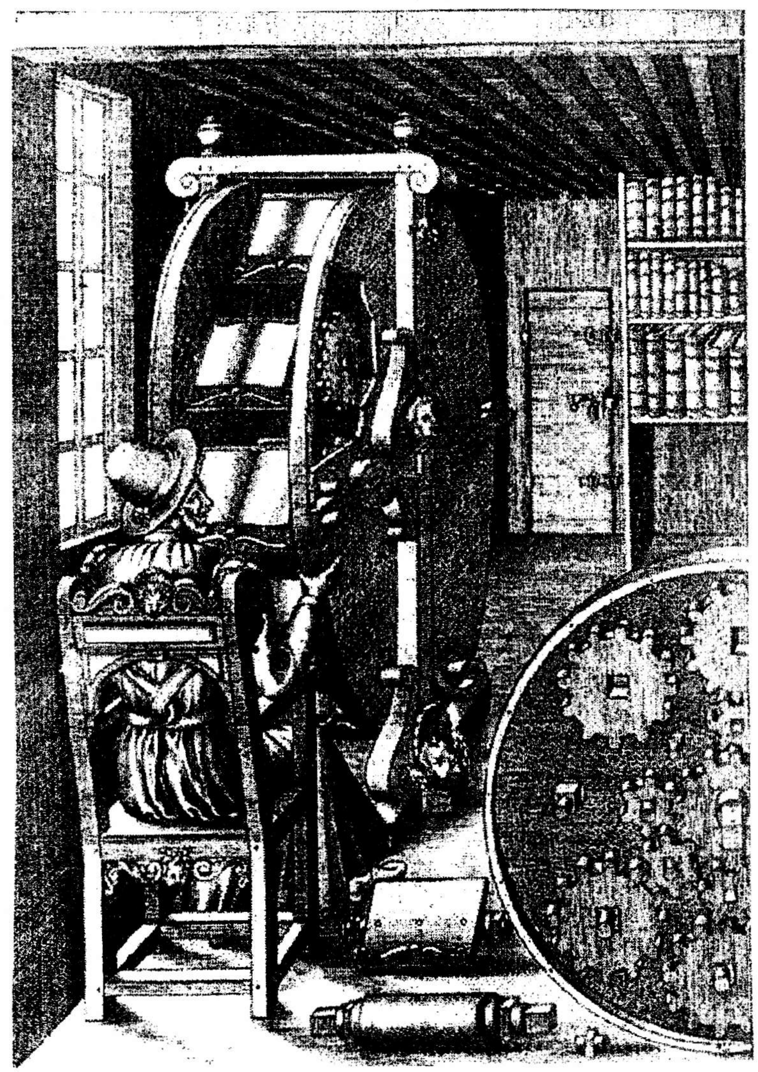
Italian Mariano di Jacopo (nicknamed Taccola, the crow), a trained sculptor, built the harbour at Genoa, and designed and developed a type of stone-throwing trebuchet. He also published two descriptive treatises, one on machines and another on engines.

Another versatile Italian artist/architect/sculptor/engineer was Francesco di Giorgio, whose reputation has rested largely on his architectural drawings and theories. In the military sphere, he built a large number of fortresses and designed battle machines and weapons. He left behind a sketchbook of machines and a translation from the original Latin of the engineering/architectural work of Vitruvius.

Agostino Ramelli, of Italian stock although, today, would be considered Swiss, is best known for his book on 'various engineering machines' published in 1588. It included lifting and water-raising machines, a suction pump, bridges, wind and other mills, what may be described as a 16th century iPad, and a possible forerunner to the Wankel engine. As a soldier, he gained a considerable reputation as a military engineer.



Ramelli's lifting machine



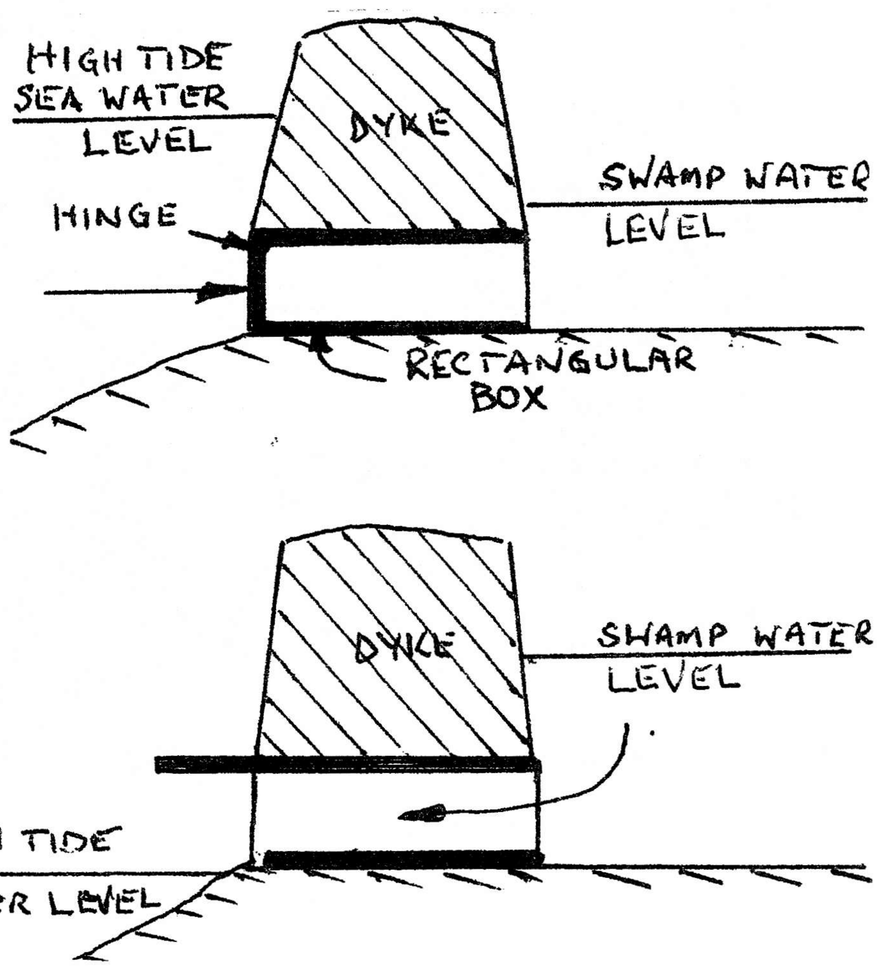
...and his 16th century iPad

Georg Bauer, a German, also known as Agricola, was a physician with an interest in mining and metallurgy. He left behind the famous book *De Re Metallica*. It recorded his experiences while visiting mines and metalworks.

While the Renaissance began in Italy, with time it spread northward to the rest of Europe and took engineering with it. Canals, for example, were built in Italy, Belgium, Britain and France. Wind and water mills drained low-lying areas, ground corn and sawed wood. The design of ships and the use of sails were influenced by the voyages of exploration, as were the design of clocks and navigation instruments. Glass and paper were manufactured. Iron became the metal of choice. Places such as Nuremberg in Germany became known as manufacturing centres, and Birmingham in England was headed the same way. The development of sugar cane in the West Indies gave rise to a whole new industry and technology.

Modern Canada began during the Age of Discovery and in the middle of the Renaissance landmark period. Before it ended, Champlain and others had left their marks on it. The early Europeans who colonized the eastern part of Canada brought their own engineering with them, but they still had much to learn from the Aboriginal peoples, who had engineered their own survival over the preceding centuries. An early Canadian/Acadian engineering development was the one-way, flap valve aboiteau, which helped drain marshy land around the Bay of Fundy.

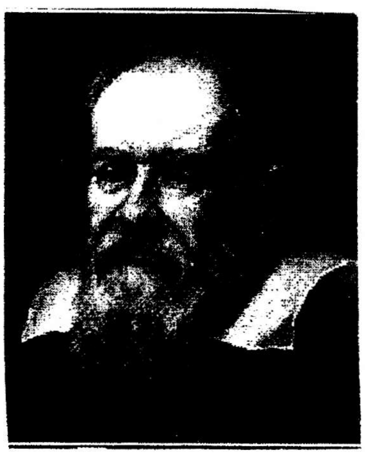
Champlain



The aboiteau

And while the Renaissance was covering Europe and other parts of the world, engineering was progressing quite separately in countries such as China and India and in the Middle East. In South America, for example, the Inca were building cities such as Cuzco and Machu Picchu and a paved highway system the length of the western edge of much of the continent.

The Renaissance was the period during which astronomers changed the world's view of itself, helped along by Galileo and his telescopes and by Copernicus, Kepler and Brache. Added to this was the beginning of the transition of engineering from reliance on experience and trial-and-error to practices increasingly grounded in experiment, science and mathematics. Contributors included Galileo, Pascal, Newton, Hooke, Boyle, Euler, Lagrange, Coulomb, Gay-Lussac, Dalton and others. Scotsman John Napier developed the logarithms that led the way to an instrument beloved for so many years by engineers, the slide rule. And of course the drawings of da Vinci and others anticipated engineering that was to come.

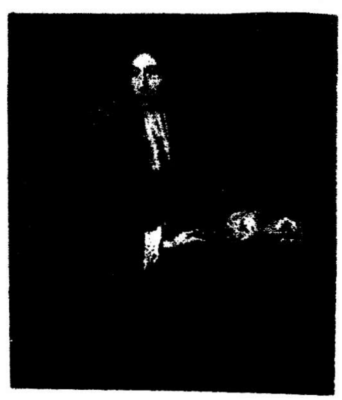


Galileo

Newton

Pascal

Napier



Boyle

Hooke

The Smeaton-to-Watt Years - 1750-1815

This third landmark period is 'anchored' by two of its major names in engineering. It includes the beginnings of modern engineering, and the works of many well-known names associated with the profession.

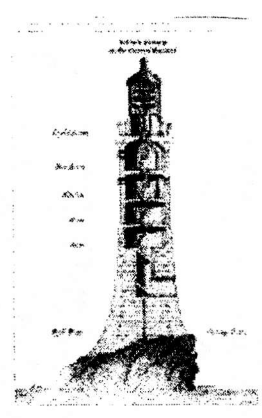
As mentioned already, it coincided with much of what, in my view, was the First (steam- and iron-based) Industrial Revolution - another European, and particularly British, phenomenon. At the beginning of it, there were no railways or steamboats, or 'learned' organizations or education systems involving engineers, as there were at the end of it. And iron was the metal of choice. The importance of these years as a landmark is that they ushered in - often modestly - what might be called 'modern engineering,' based on new ideas and somewhat larger scale production, and established engineering as a profession.

The use of steam engines, particularly for pumping engines to raise water from mines, began in the late 17th and early 18th century with the work of France's Denis Papin and England's Thomas Savery and continued with developments by Thomas Newcomen. But these engines were very inefficient. Watt's renown, but not Smeaton's, was linked to the improvement of this efficiency. The years covered by this landmark were those in which these two men were most active.

This landmark period was full of wars, including the Seven Years' War, which involved the French and Indian War in North America, the siege of Louisbourg and the Battle of the Plains of Abraham in Canada, and the ceding of New France to Britain. And there were the French and American Revolutions, the Napoleonic Wars in Europe and the War of 1812 between British North America and the new United States.

Englishman John Smeaton was born in 1724 and died in 1792.

John Smeaton



...and his Eddystone Lighthouse

Much of Smeaton's reputation rests with his work in the design and construction of the third Eddystone lighthouse, some 15 miles off the Devon coast, opposite Plymouth, that was completed in 1759. It was made of granite blocks rather than wood, and the blocks were dovetailed together for added strength. He was influential in the design and construction of the lighthouses built later elsewhere. Smeaton also 'rediscovered' the hydraulic cement first used by the Romans and then forgotten for 700 years. In the mechanical field, he developed waterwheels, designed and built a cylinder boring machine, and made improvements to Newcomen steam engines and to diving bells. His other English and Scottish civil engineering commissions included:

- the Coldstream Bridge over the River Tweed;
- improvements to the navigation of the River Lee;
- the Perth Bridge over the River Tay;
- the Ripon Canal;
- the viaduct over the River Trent between Newark and South Muskham in Nottinghamshire;
- the Forth and Clyde Canal from Grangemouth to Glasgow;
- Banff harbour works;
- Aberdeen Bridge;
- Peterhead harbour works;
- Ramsgate harbour works;
- the Hexham Bridge;
- the Birmingham to Fazeley Canal; and
- Charlestown harbour works at St, Austell.

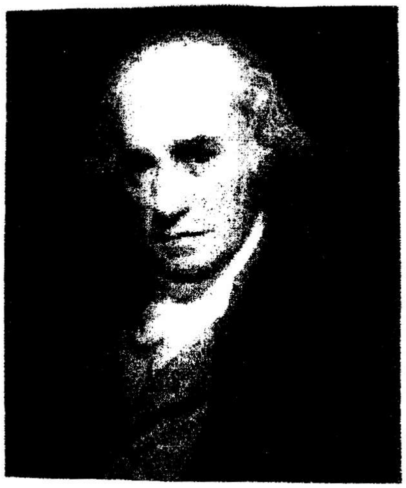
Smeaton was reputed to have been the first to have called himself a *civil* engineer, as distinguished from a military one and to have firmly fixed engineering as a recognized profession. He was the first engineer-expert witness to testify in an English court.

Smeaton was also the driving force, with Robert Mylne, the bridge builder, behind regular meetings of senior civil engineers held at a London tavern, beginning in 1771, at which the business of the profession was discussed. Called the Society of Civil Engineers, its meetings became dinner rather than tavern ones after Smeaton's death in 1792. However, junior members of the profession resented their exclusion, with the result that the Institution of Civil Engineers was founded in 1818 to include all civil engineers and was the first of the handful a of 'learned' societies established in Britain within the profession as a whole. The SCE was renamed the Smeatonian Society in 1830. Still consisting of senior civils, it continues to meet to this day.

Scotsman James Watt was born in 1736 and died in 1819.

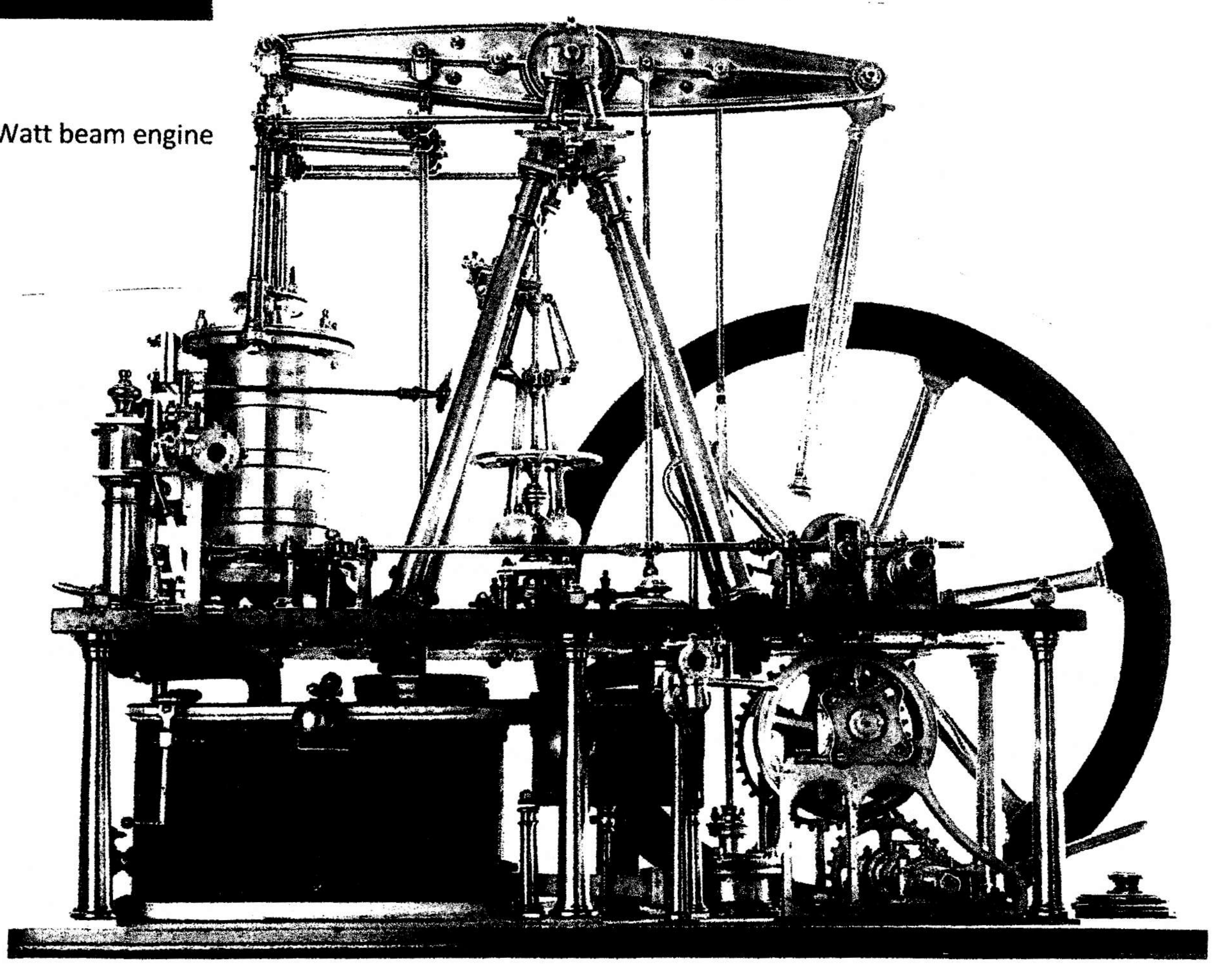
Watt is often described as having been a mathematical instrument maker serving the University of Glasgow. He was much more. His father was a merchant in the Clydeside town of Greenock who also built ships, made nautical instruments and had a workshop in which his son - among other things –

learned to build models from wood and metal. He did indeed train as an instrument maker and set up his own business. He also acquired a scientific aptitude and turn-of-mind, becoming unusually inventive mechanically. He was involved, as Smeaton was, in the building of the Forth-Clyde Canal across central Scotland. And he made useful friends among the University of Glasgow staff.



James Watt

...and a Watt beam engine



In 1764 Watt was asked by the University to improve the performance of its energy-wasting Newcomen pumping engine. His solutions - a separate condenser and lubrication to reduce friction - made Watt's engine more efficient. By 1776 he had formed a partnership with Matthew Boulton, of Soho, Birmingham, to manufacture it. Within a few years, Watt had devised a double-acting beam engine (with a speed governor) that could convert vertical into rotary motion. He protected his inventions with patents. Boulton & Watt sold the engines world-wide for both land and marine applications.

Both Smeaton and Watt were members of the Lunar Society of Birmingham, another informal dinner and discussion club, but this time with a much broader membership. Erasmus Darwin, Charles' grandfather, was a member, as was chemist Joseph Priestley, pottery manufacturer Josiah Wedgewood, astronomer William Herschell, and Watt's business partner, manufacturer Matthew Boulton. It had a much wider irregular membership - Benjamin Franklin, for example. The Society took its name from the fact that there was no street lighting at the time and night-time city streets could be dangerous. So the members met on the Sundays nearest the full moon.

Among the many engineering achievements made by others during the landmark Smeaton-Watt years were these:

In 1754 the first iron rolling mill went into service in England.

James Brindley completed his first canal for the Duke of Bridgewater in 1761, enabling His Grace to transport coal from his mines to its Manchester market. It was just one of several notable contemporary European waterways.

In 1765, Englishman James Harrison received a prize for building an accurate chronometer that could be used to measure longitude at sea.

In 1775, Frenchman Pierre-Simon Girard invented the water turbine.

The first cast iron bridge was erected at Coalbrookdale in Shropshire, England, in 1779 by Thomas Pritchard, using material made from pig-iron produced by the more efficient coke-based process developed by three generations of Abraham Darbys in a nearby plant.

In 1780, Aimé Argand, a Swiss, invented the 'chimney' oil lamp, a variant of which was used to light the early modern lighthouses around Europe's coastlines.

By 1780, Englishmen Joseph Bramah and Henry Maudslay had established high precision manufacturing, enabling machine parts to be made in bulk rather than singly;

The Montgolfier brothers made the first manned ascent in a hot air balloon in France in 1783.

In 1784, Henry Cort, in England, developed a method for producing satisfactory wrought iron.

Also in 1784, Scotsman Andrew Meikle invented the threshing machine.

In 1789, shipbuilder William Fairbairn developed a riveting machine for steam boilers.

L'Ecole Polytechnique began educating French scientists and engineers in 1794, almost 50 years after L'Ecole des Ponts et Chaussées had begun educating civil engineers. By contrast, contemporary engineering education in Britain during the Smeaton-Watt years, and for many decades to come, was based on apprenticeships and pupilage. The first Regius Chair of Engineering in Britain was not established there until 1840, at the University of Glasgow. Formal academic education in engineering in the United States dates from the 1820s and, in Canada, from the 1850s.

During this third landmark period, Richard Arkwright, Samuel Crompton and James Hargreaves in Britain, Joseph Jacquard in France, and Eli Whitney in the United States contributed significantly to the development of textile engineering.

Bramah's famous hydraulic press had been developed in England by 1795.

In 1800, Richard Trevithick, a colleague of Watt and Boulton, built his first steam locomotive. By 1808 he was demonstrating a later model on an enclosed circular track to the general public.

Also by 1800, Italian Alessandro Volta had developed the first battery to produce a steady supply of electric current.

In 1801, James Finney built the first modern suspension bridge in the United States.

In 1805, Oliver Evans built the first steam-powered vehicle in the United States. And around this time, Pittsburgh became America's 'iron city.'

Also by 1805, Scottish engineer Thomas Telford had built the Pontcysyllite Aqueduct in Wales.

In 1807, another Scot and another colleague of Watt and Boulton, William Murdoch, lit London streets with gaslight.

Also in 1807, Fulton's *Clermont* steamboat was put to 'economical use' on the Hudson River at New York, five years after Symington's *Charlotte Dundas* was tried out as a tugboat on Scotland's Forth-Clyde Canal, and two years before John Molson's *Accommodation* began work on the St. Lawrence River.

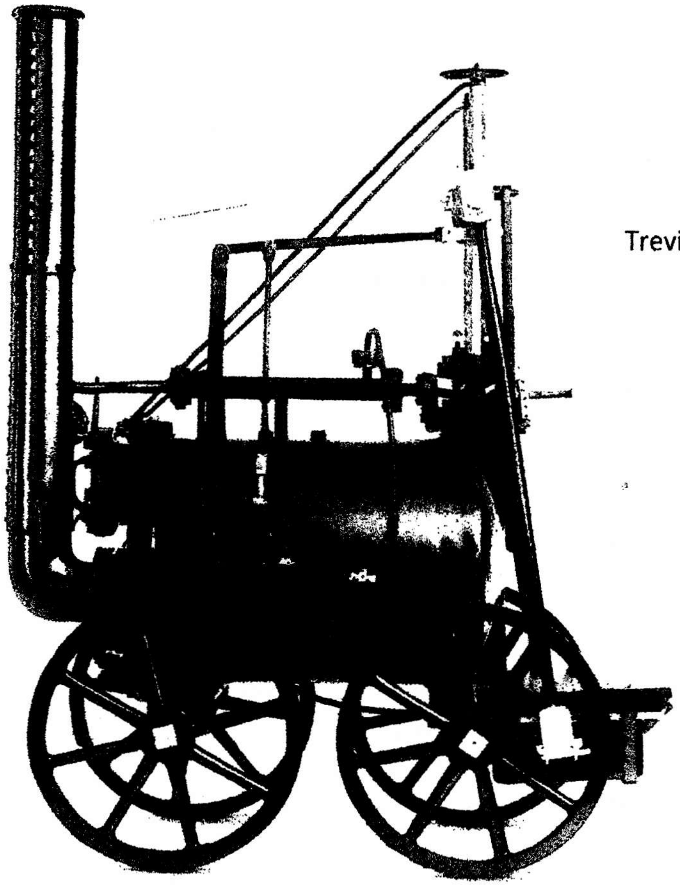
Using engineering pioneered by John Smeaton, Robert Stevenson designed and built the Bell Rock lighthouse off the Scottish coast from 1807 to 1811. Later, his sons and grandsons built many more using the same techniques.

In 1810, Friedrich Krupp established his family's steel plant at Essen, in Germany.

In 1814, George Stephenson built his first steam locomotive.

Also in 1814, the *Times* of London was being printed by a steam-driven cylinder press.

In 1815, the first warship powered by steam was built in the United States; the Humphrey Davy safety lamp was used in British mines; and John Loudon McAdam introduced crushed rock paving for roads.



Trevithick steam locomotive

Pontcysyllite Aqueduct

The International Exhibitions Sandwich -1851-1876

The 1851 Exhibition was held at the Crystal Palace in Hyde Park, London, England, to celebrate British leadership, self-confidence and achievement over the century just passed, and the 1876 Exhibition was held at Philadelphia, Pennsylvania, to celebrate the centennial of the United States. Both exhibitions included contributions from countries other than the hosts.

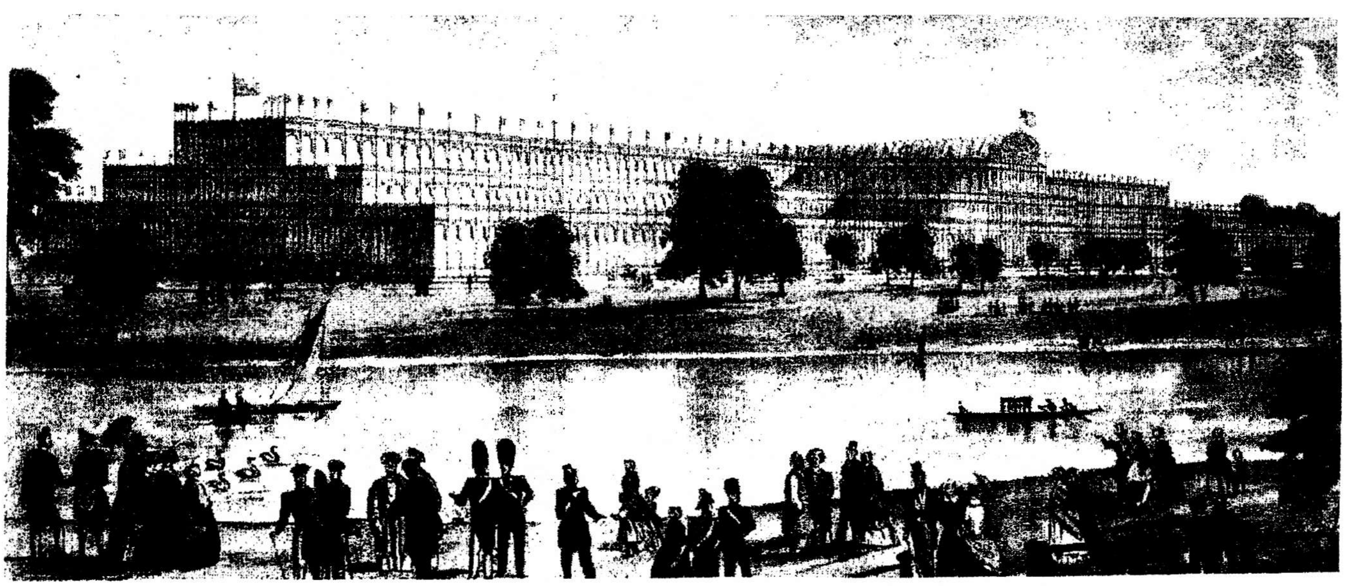
It is a landmark period since it also saw the beginning of the decline of British dominance in the world of engineering and the beginning of the growth of U.S. leadership in it, which has continued up until the present time.

Queen Victoria's husband, Prince Albert, and the British Government took an active interest in the 1851 Exhibition. The United States President and Government were not active participants in the 1876 one.

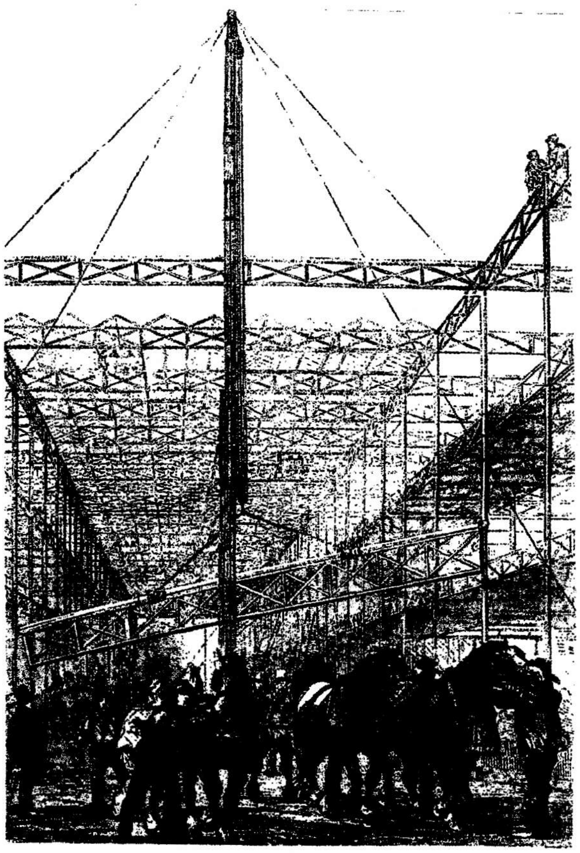
The principal wars affecting Europe and North America during this period were the Crimean, American Civil and Franco-Prussian Wars.

In my view, this landmark period also began the Second Industrial Revolution, which was based on transportation, steel and electric power and lasted until the end of World War II.

The Crystal Palace was, itself, an engineering achievement of considerable magnitude. Designed by Joseph Paxton, whose previous experience of large glass buildings was limited to greenhouses, it took advantage of the recent development of strong but cheap cast plate glass. Among its components were 300,000 panes of this glass and 4,500 tons of cast iron. The Exhibition building was almost 2,000 feet long and the arched centre transept was 130 feet high. The building was divided into 'courts' with different themes. The 13,000 exhibits from all around the world were seen by over 6 million visitors. Britain and its Empire, including Canada, occupied half the available exhibit space.



The Crystal Palace, 1851

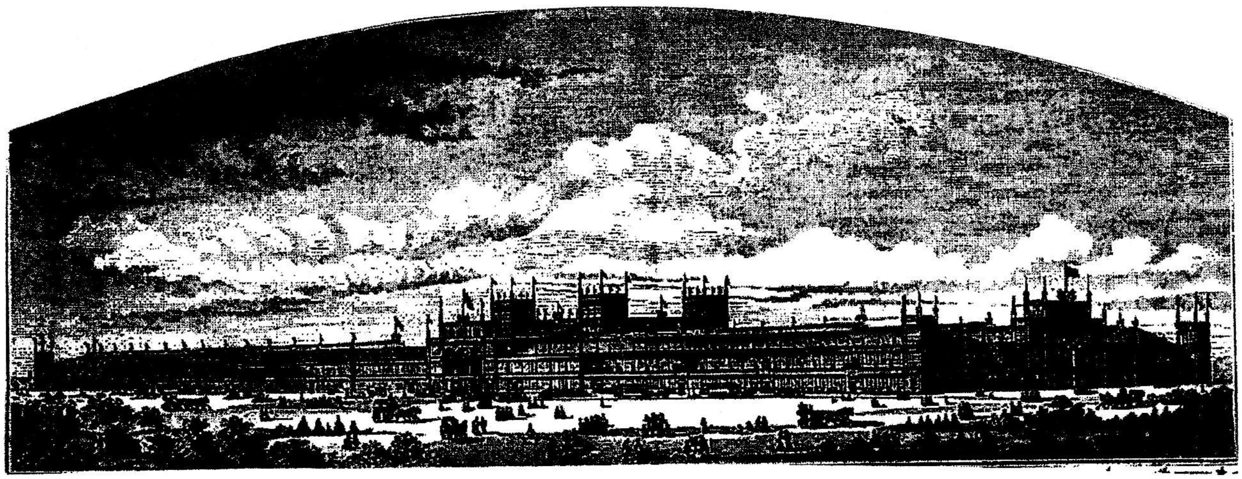
The Crystal Palace under construction

It was at this Exhibition that Englishman Joseph Whitworth demonstrated his micrometer, which he claimed could measure to an accuracy of one-millionth of an inch. He also demonstrated high precision machine tools for drilling, planning, slotting and boring. Also exhibited were a steam hammer that could forge an engine shaft - or crack an egg, adding machines, a super-fast printing machine, elegant horse-drawn carriages and early bicycles, textile and agricultural machines, steam engines and locomotives. There was also a Canadian fire engine and an Indian howdah. France sent tapestries, furniture and ceramics and the machines that made them.

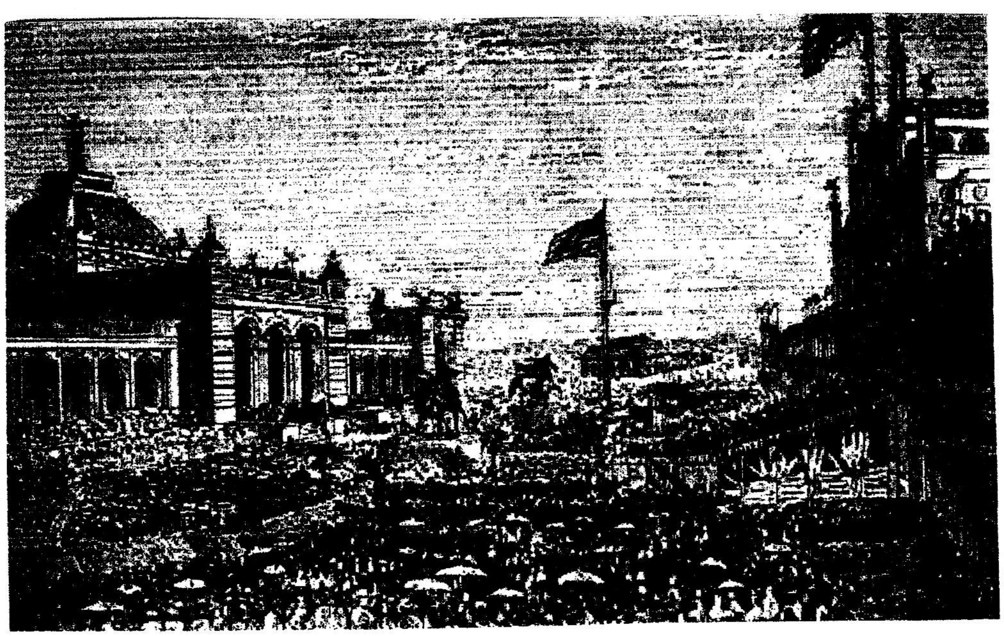
In 1854, the Crystal Palace building was relocated to, and re-erected at, Sydenham in Kent. Over the years, it served a variety of purposes. It was destroyed by fire in November 1936.

The Centennial Exhibition (and the first U.S. World's Fair) at Fairmount Park, in historically-appropriate Philadelphia, was opened on May 10, 1876 by President Grant of the United States and Emperor Dom Pedro II of Brazil. Unlike Prince Albert, the President was not an active participant in the preparations for Philadelphia.

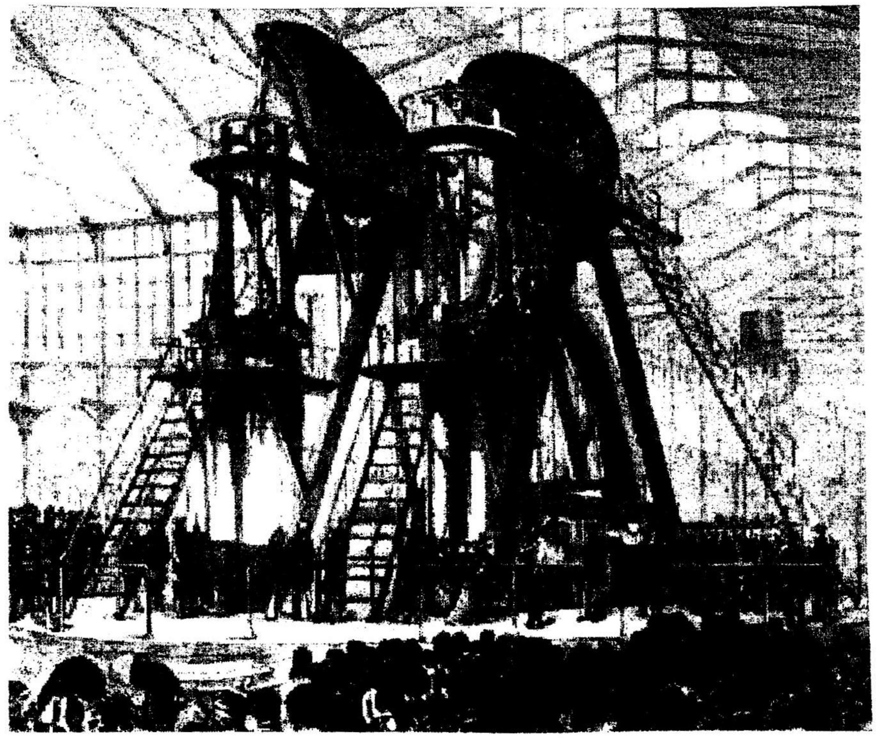
A bill to establish a United States Centennial Commission was passed by Congress in March 1871, but the U.S. Government declined to be responsible for expenses in regard to the Exhibition. Commissioners were appointed to represent each state and territory then members of the Union. In June 1872, Congress created a Board of Finance to arrange funding for the exhibition, which it did through a stock issue. Philadelphia and Pennsylvania also contributed. Congress contributed a loan. In 1873 the Commission appointed a director-general. 450 acres of Fairmont Park were set aside for the Exhibition. More than 200 buildings were constructed over the next three years, surrounded by a three-mile-long fence. The largest was the Main Building, which covered almost 22 acres. It was of wood and frame construction, with ample glass to let light inside. The next largest, the Machinery Hall, covered 14 acres. In all, there were over 20,000 exhibits. When the Exhibition closed in November, some 8 million visitors had passed through the gates.



The Philadelphia Exhibition, 1876



The principal exhibit in the Machinery Hall was an enormous 2-cylinder Corliss steam engine, the largest in the world. It was around 60 feet high, with a 30-foot diameter flywheel, and weighed over 600 tons. It was fed steam from multiple boilers located in another building. Through extensive belting systems, it drove the other machinery in the Hall. President Grant, assisted by the Emperor, officially started it up on Opening Day.



The Corliss steam engine

Alexander Graham Bell, by then a Boston resident, won the gold medal in the electrical section for his telephone exhibit and demonstration - thanks in large measure to the intervention of the Brazilian Emperor! The chairman of the committee awarding the medal was Sir William Thomson, later Lord Kelvin. The story of how this happened had been told by Ottawa author Charlotte Gray in her book *Reluctant Genius*.

The Pennsylvania Railroad exhibited a steam locomotive originally built in 1831. Waltham Watch displayed its first automatic screw-making machine, Wallace-Farmer an electric dynamo, and Remington demonstrated its new typewriter. One of the notable outdoor exhibits was a replica of what would be the right arm and torch of the Statue of Liberty.

Americans Cyrus McCormick and Samuel Colt demonstrated the mechanical reaper and the repeat action revolver, both of which used interchangeable parts, which would lead eventually to mass production techniques of 50 years later.

After the Exhibition, some of the exhibits were transferred to the Smithsonian Institution in Washington. The Corliss engine found a home in Chicago. Most of the buildings were taken down. Fairmont Park was cleared and reverted to being Philadelphia's recreation space.

Contributions to the development of engineering during this landmark period included the following:

First was the production of steel, which was replacing iron with a much less brittle, and much stronger, material for building many things.

The name *Bessemer* is synonymous with the production of steel. The converter, which made steel-making commercially feasible, was Henry Bessemer's device - developed in Britain. It speeded up the process of converting the original pig iron into steel and did so more cheaply than earlier competing processes. It was patented in 1855. The subsequent application of steel to skyscrapers, bridges, ships, rails, locomotives, boilers, guns and other machinery and devices spearheaded technological change in the years that followed.

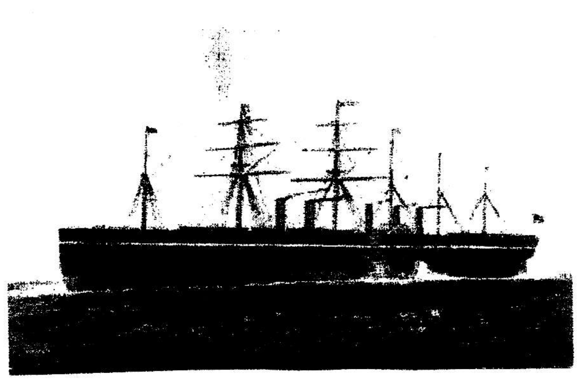
Alexander L. Holley, a mechanical engineer, purchased the U.S. rights to the Bessemer process and, as a consulting engineer, proceeded to modify it for American use, beginning in the 1860s. One user was Andrew Carnegie's Edwin Thompson plant at Pittsburgh.

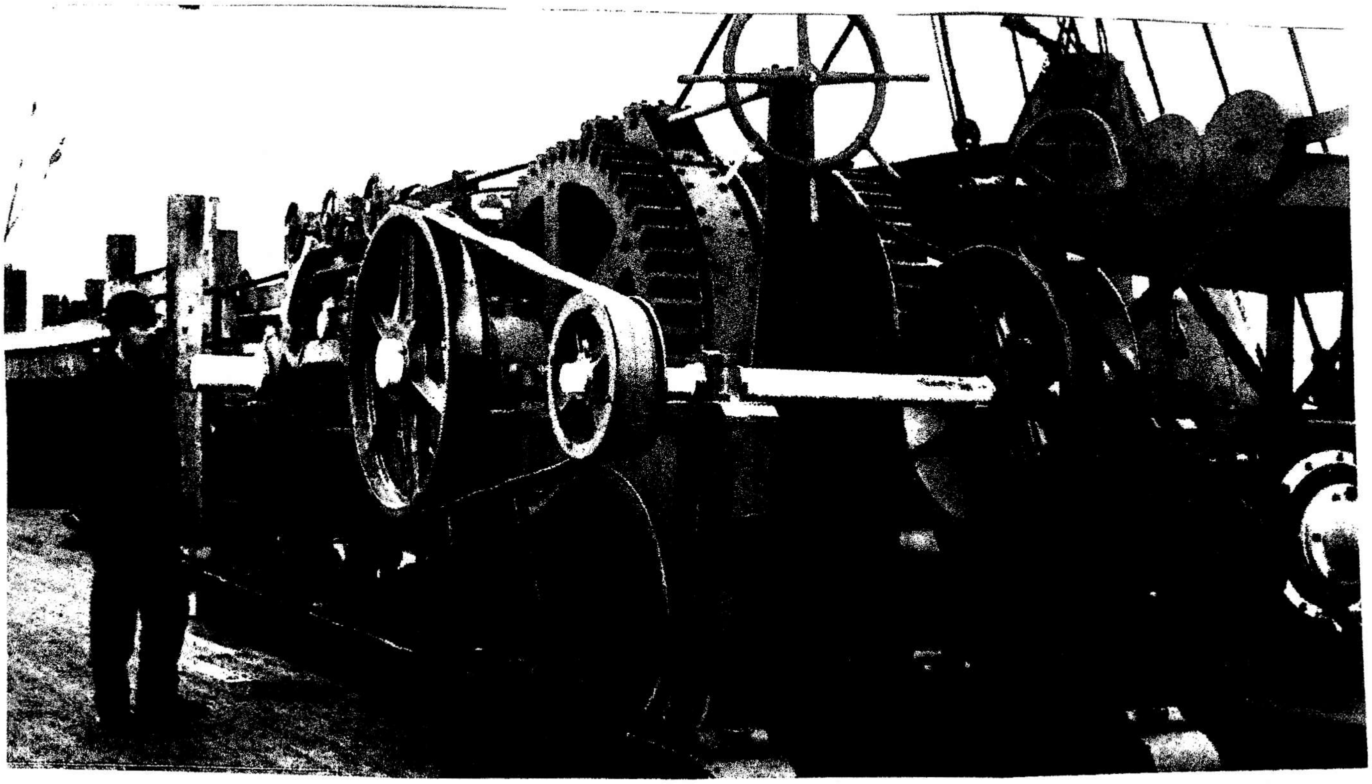
Perhaps the best-known of the British engineers during the 'two Exhibitions' period was Isaac Kingdom Brunel, son of eminent engineer Sir Marc Brunel who built the first Thames Tunnel and which his son completed. The younger, and more controversial, Brunel is well known for building Britain's Great Western Railway and for his several bridges, harbours and other works. But perhaps his most spectacular achievements were the design and construction of three ships, the *Great Western,* the *Great Britain,* and the *Great Eastern.* The first (1838) had a wooden hull and iron trusses and was the first steamship to make regular voyages across the Atlantic. The second (1845) was the first large iron ship and the first to be fitted with a screw propeller.

The third ship belongs to this fourth landmark period. When launched, it was the largest ship afloat, had a double hull and was propelled by both paddles and screws. It was not a commercial success as a passenger liner but succeeded as the layer of Atlantic telegraph cables. One of its principal advantages was that it could carry, in its holds, the entire transatlantic cable.

The technical man behind these cables was Scotsman William Thomson, a physicist by profession, who also functioned as an engineer - and later became Lord Kelvin. In 1856 he joined the board of the Atlantic Telegraph Company, to lay the cable between Britain and the United States.

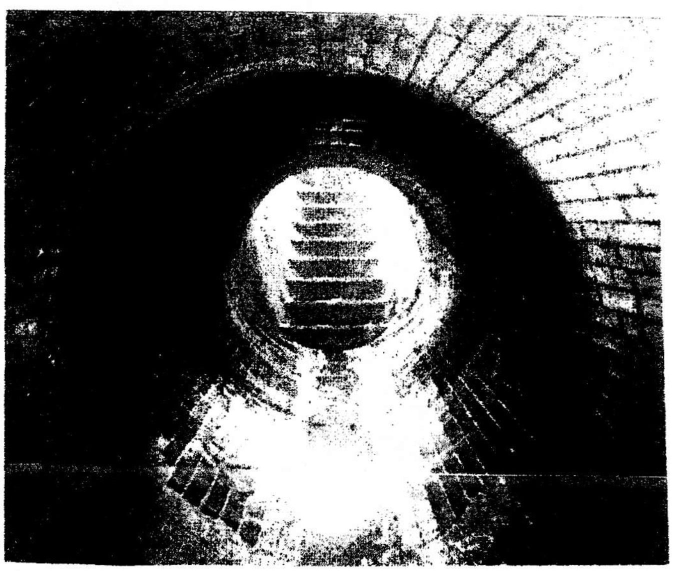
The *Great Eastern*

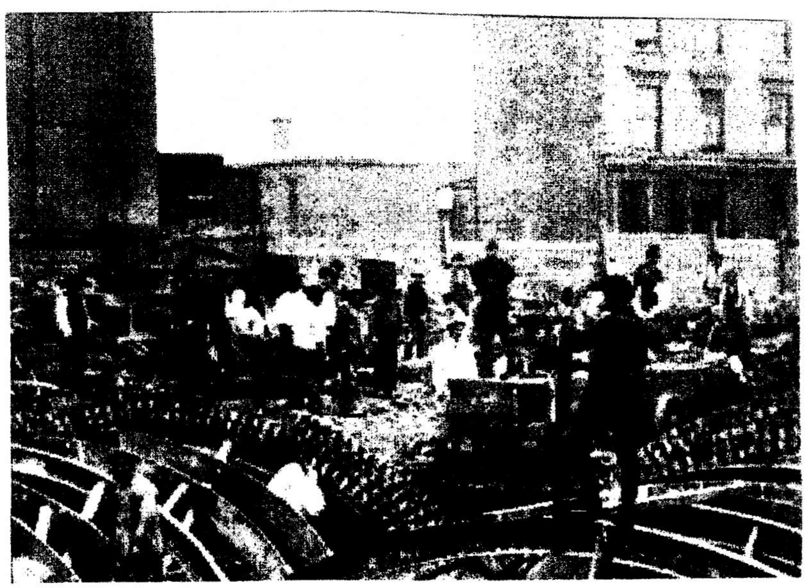




Cable-laying machinery, the *Great Eastern*

One of I.K. Brunel's friends was civil engineer Joseph Bazalgette. His contribution to the engineering of the 1860s was London's remarkable sewage system. Before it was built, cholera and other epidemics had brought death to thousands. The 'great stink' of 1858 persuaded the British parliament to fund a complete rebuilding of the existing open system. The new, closed, one was designed and built under Bazagette's supervision. It was opened in 1865 and completed in 1875, and is still in use today.

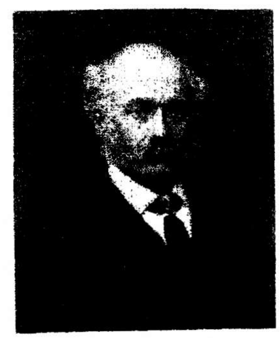


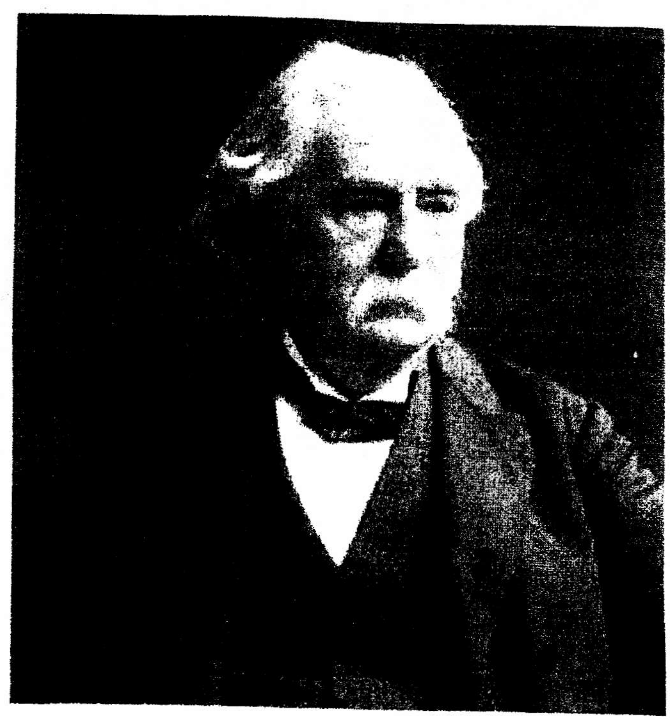


Bazalguette's London sewer system

Eugène Belgrand did for Paris what Bazalgette had done for London sewage and, in addition, secured its water supplies.

A Canadian contribution was made, in Hamilton, Ontario, by Thomas Coltrin Keefer, who designed a number of municipal water systems in Eastern Canada. The pressure for the Hamilton one came, again, from cholera and smallpox epidemics. Built by the city, it would improve the quality of life there and provide a reliable source of water to fight fires. The water was drawn from nearby Lake Ontario. The two 100 hp compound steam pumping engines were designed and built at John Gartshore's plant at Ancaster and were based on the Boulton & Watt 30-foot walking beam engine design. The flywheels were 24 feet in diameter. The original four boilers were wood-fired, and the pumping capacity was over 3 million gallons per day. It was opened in 1859.



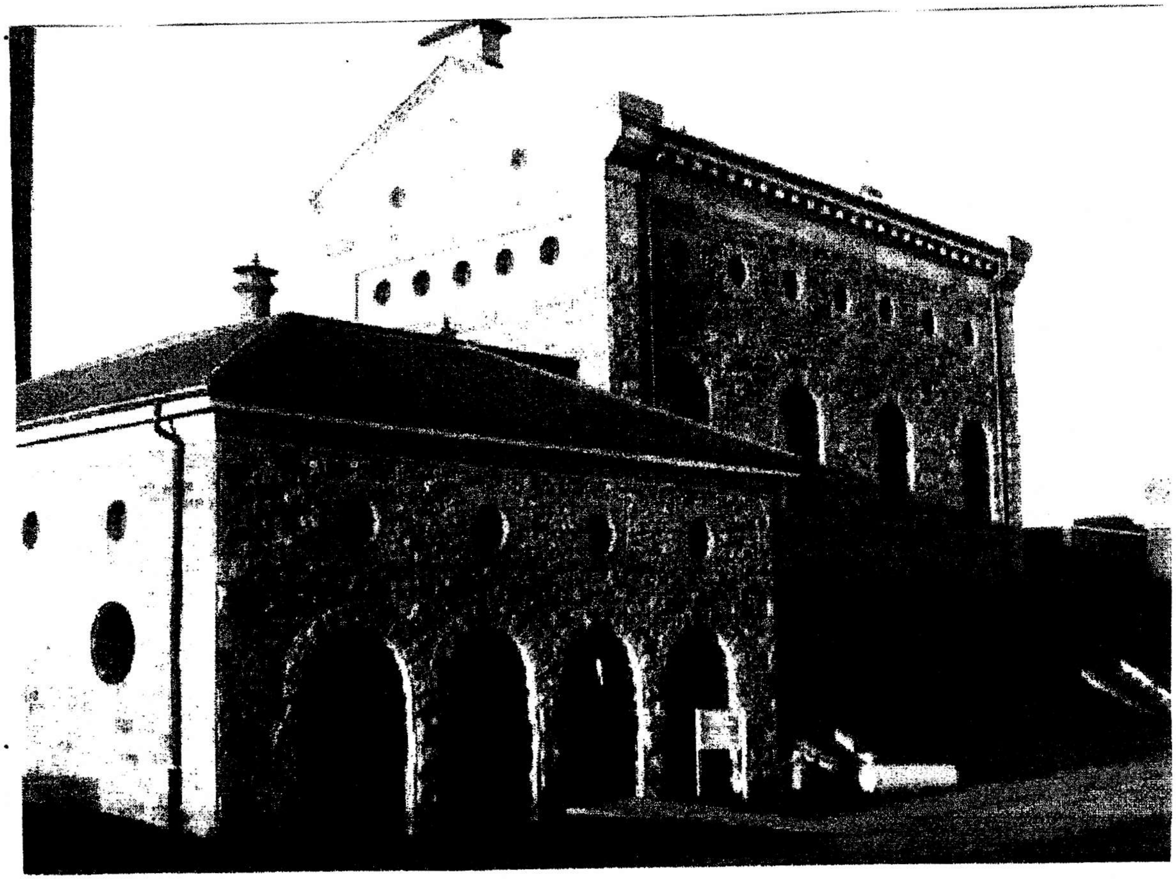


I.K. Brunel

Eugène Belgrand

Sir Joseph Bazalgette

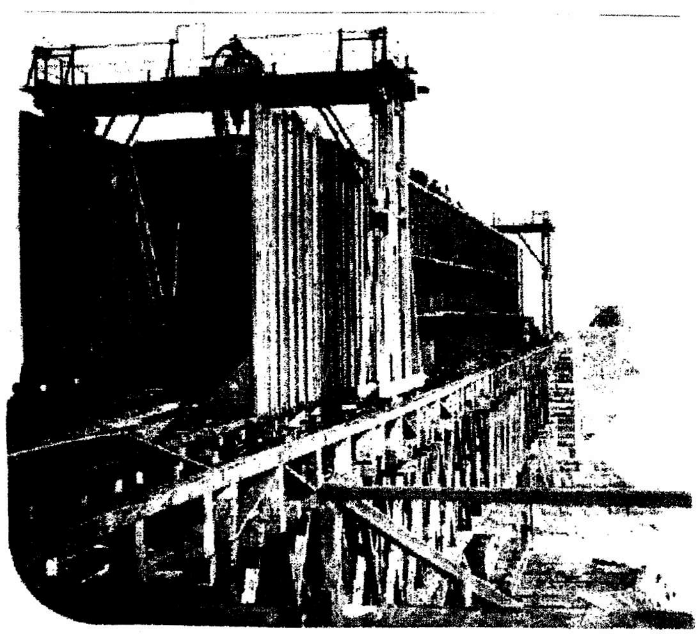
T.C. Keefer

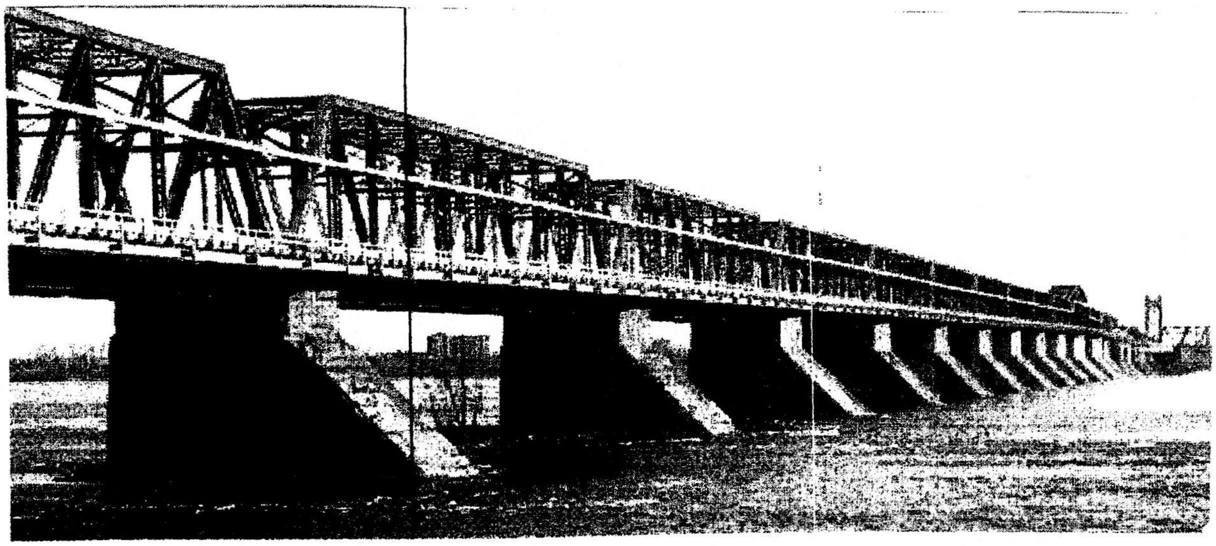


Hamilton's Old Pumphouse, 1859

The year 1859 also brought to completion a second Canadian engineering achievement - the design and construction of the original Victoria Bridge over the St. Lawrence at Montréal. The original design was based on Robert Stephenson's wrought iron tubular bridge over the Menai Strait in northwestern Wales, which was opened in 1850. Stephenson was a consultant for the design and construction the St. Lawrence bridge, as was T.C. Keefer. However, the 'tube' did not work and the superstructure was soon replaced.

Building the original Victoria Bridge





Victoria Bridge, Montréal, today

Another well-known father-and-son engineering team were the Roeblings, John and Washington, and their most visible achievement was the design and construction of the suspension bridge that links Manhattan with Brooklyn. Prior to this, suspension bridges had the reputation of being fragile, and the East River's winter ice for being dangerous. So the Brooklyn Bridge was essentially over-designed. Work began in 1869. The first suspension wires were strung between the bridge's towers in 1876 and the bridge was completed in 1883.

Among some of the other significant engineering achievements during this fourth landmark period were the following:

The Ruhr became the first German region to develop into an industrial heartland; this process was accelerated in the mid-1850s by the development of its many coal mines and the use of coke in steel production.

Elisha Otis invented the 'safety' elevator in 1852; the company he founded the following year became the world's largest manufacturer of vertical transportation systems; these systems, along with the development of steel structures, led in time to the construction of much taller buildings and, by the late 1880s to the world's first skyscraper.

The first oil refinery in Canada was built in 1857, the first in the United States in 1859; the first oil pipeline in Canada was built in 1862, from Petrolia to Sarnia.

The first underground train in London ran in 1863.

Alfred Nobel, in Sweden, invented dynamite in 1867 - which made nitro-glycerine safe to use, and the even more powerful gelignite in 1876.

Also in 1867, at a meeting of the Berlin Academy, Werner von Siemens (one of three engineer brothers) presented his invention of a direct current generating dynamo.

The Suez Canal was opened in 1869.

The 'last spike' ceremony marking the completion of the first U.S. transcontinental railroad was 'driven' in Utah in 1869; the 'last spike' for the first Canadian transcontinental railway was not driven in British Columbia until 1885.

The world's first reinforced concrete bridge (54 feet long) was built in 1875 by French gardener Joseph Monier in 1875.

Until the mid-19th century, the main disciplines of non-military engineering had been civil, mechanical and mining. Then they were by joined embryonically by the emerging disciplines of electrical, chemical and aeronautical engineering.

Although Morse's telegraph had been in service since the 1830s, and Bell's telephone would go into service after 1876, the electrical discipline was more of a branch of physics during this fourth period than an engineering one. Its principal knowledge/innovation contributors included Hans Oersted, Michael Faraday, Joseph Henry, Charles Wheatstone and James Clerk Maxwell. The early practitioners of the chemical discipline were better known as 'industrial chemists,' concerned with the batch processing of materials such as soap, oils, fuels, and water and its purification and testing. In the aeronautical field there was the work of George Cayley on the physics of flight, and of Stringfellow and Henson on un-manned power flight.

Since much of the work being done around this time in the new disciplines was experimental and not just theoretical, it replaced the trial-and-error practices of earlier engineers with scientific ones. And science became, progressively, more useful as the basis for advances in engineering.

This fourth landmark period also saw the beginnings of professional education for engineers in Canada and the United States. For example, while the first courses in engineering in North America had been given at the U.S. Military College at West Point and at the Rensselaer Polytechnic Institute in the 1820s, the first in Canada, at the University of New Brunswick, were given in the 1850s. The Morrill Act in the U.S. established the Land Grant colleges, and many engineering schools in the U.S., beginning in 1862 - the year after the Massachusetts Institute of Technology opened at Cambridge. MIT took the French academically-based, research approach to teaching, in contrast with the more practical approach adopted by the British schools of engineering.

I should also mention that, while the American Association for the Advancement of Science was founded in the 1840s, the first U.S. professional engineering society - for civil engineering - was founded in 1852, and for mining engineering in 1871. The first Canadian 'learned' professional society - the Canadian Institute - was started in 1849 by a few engineers, architects and land surveyors, led by Sandford Fleming. The first professional *engineering* society - the Canadian Society of Civil Engineers, with 'civil' being opposed to 'military' - was not founded until 1887.

Speaking of Canada, it became a Confederation of provinces in 1867.

The Turn of the 20^{th} century - 1890-1905

The dominant reasons for this being my fifth landmark period were the beginnings of aviation, the arrival of cars and trucks, gasoline and oil engines, the development of large-scale hydro-electric plants generating alternating current....and the discovery of 'pieces' of the atom.

The subordinate reasons were many and included the building of skyscrapers and some very large steel ships, the design of machinery based on both direct and alternating current electricity, the birth of wireless/radio and motion pictures, the development highway systems, and the production of chemical and metal products on a large scale. And from this landmark onwards, the importance to engineering design of theory and of scientific research gradually increased, although the need for good, sound engineering practice never did decline.

The principal international conflicts were the Boer, Russo-Japanese and Spanish-American Wars.....with World War I to follow.

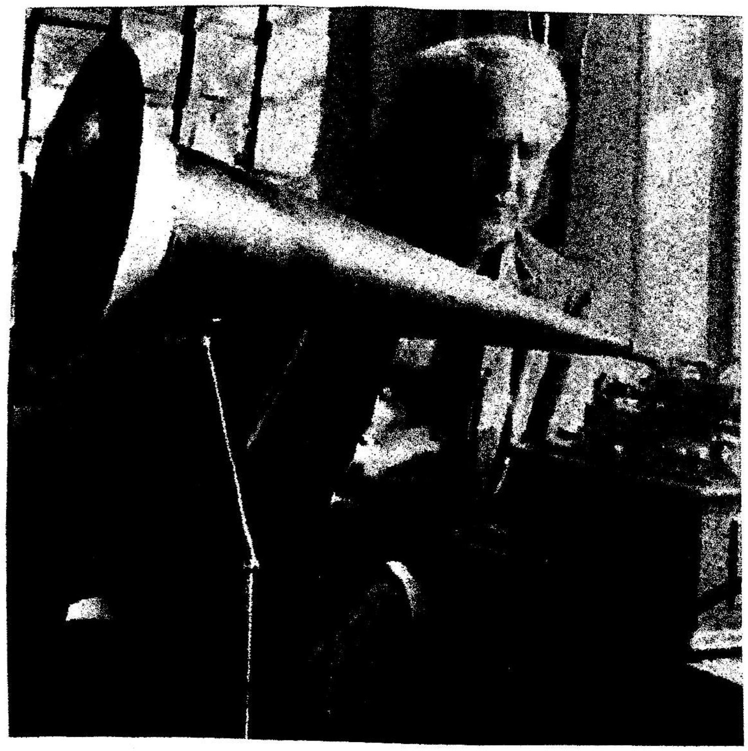
This period included two vigorous personal rivalries involving the development of electric power and the wireless transmission of sound: Thomas Edison versus Nikola Tesla over D/C or A/C electric current for power generation and other applications; and Tesla versus Guglielmo Marconi over the wireless transmission of sound (leading to the development of radio). The difference between the men may be characterised by the fact that Tesla was more scientist than engineer and tended to rely on theory and experiment, while the other two were the opposite, favouring trial, error and experiment, with the theories usually developed by others. Also, Edison and Marconi were good businessmen. Tesla was not.

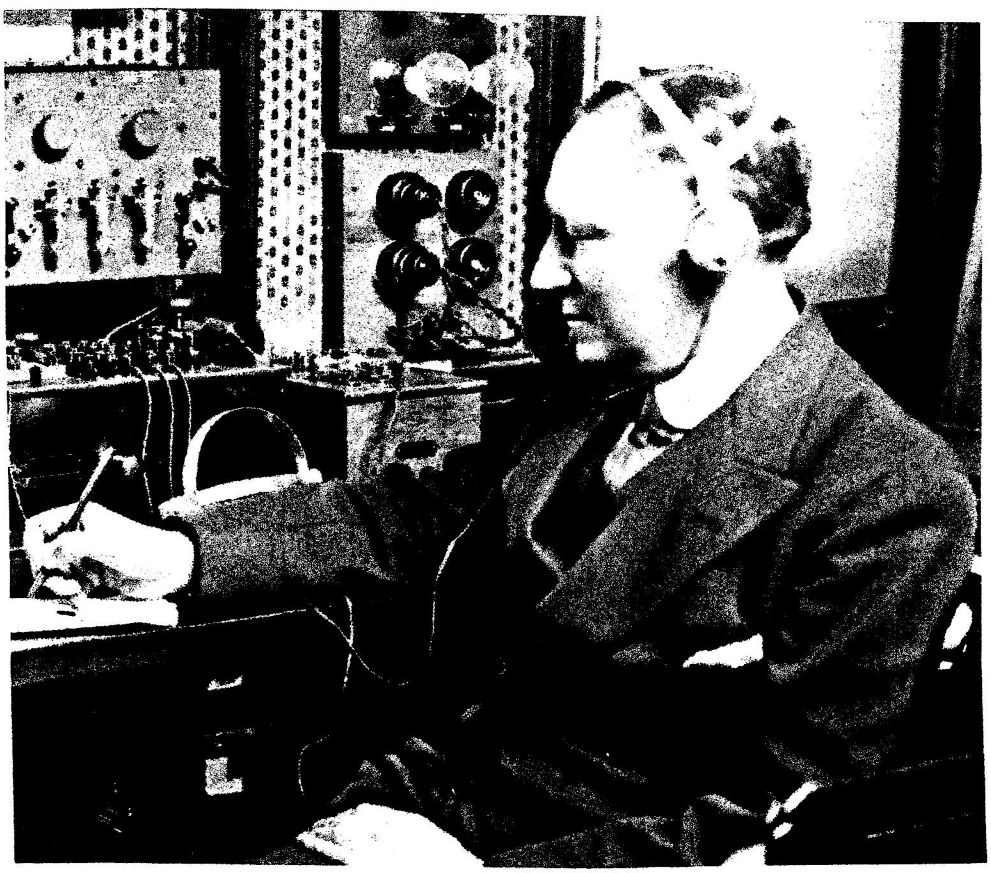
It was while Tesla was working for Edison in New York that the DC/AC business reached its head. It is usually referred to as 'the war of the currents' of the 1890s. It began earlier, in Budapest, when Tesla developed the A/C induction motor. No one in Europe was interested in it, so he crossed the Atlantic to try to sell it to Edison, who was also not interested, having made a significant investment in direct current, which he developed and patented, and which generated power that his company supplied to the city of New York. Because alternating current could be transported over greater distances at higher voltages Tesla won this argument, and it was George Westinghouse who helped him do so.

Another Tesla breakthrough came in 1891 when he invented a type of transformer that could produce pulses of high frequency, high voltage A/C, which became known as the 'Tesla coil' and which, he believed, would help him in the development of the wire-less transmission of energy. This brought him into conflict with Marconi. Tesla filed his first radio patent application in 1897. Unfortunately, fire destroyed his laboratory and research records and undermined his ability to fight off Marconi's challenge.

Marconi based his invention on the discoveries of Heinrich Hertz, who had produced and detected electromagnetic radiation. Thwarted in his native Italy, Marconi went to England to pursue his work and, over the next few years, successfully sent wireless signals over increasing distances. By 1899 he had sent


Tesla


Edison


Marconi

wireless communications across the English Channel. And in 1901 he used a transmitter in Cornwall to send his famous message - a single letter of Morse code - across the Atlantic, to Newfoundland. By so doing, he began his entrepreneurial career, backed by such people as Thomas Edison and Andrew Carnegie.

The competition between Tesla and Marconi for the U.S. radio patent began in 1900, and was decided in Tesla's favour. But four years later, U.S. Patent Office reversed itself in favour of Marconi. Tesla, apparently, did not then have the resources to fight this decision. In addition, at the beginning of World War I he lost the royalties from his European patents. Marconi also won the Nobel Prize for physics in 1909. Finally, in 1943, six years after Marconi's death and a short while after Tesla's, the U.S. Patent Office reversed itself again - in Tesla's favour.

Otto Lilienthal is quoted as having said, "To invent an airplane is nothing; to build one is something; but to fly is everything." During this landmark period, all three were done.

Prussian-born Lilienthal and his brother Gustav began the process by designing, building and flying gliders. Otto, an engineer and boiler and steam engine manufacturer, experimented with ornithopters and studied the theory of flight. In 1891, when he began experimenting seriously, he was using gliders, although other pioneers were already developing un-manned powered flights. In the five years between then and his death in a flying accident, he made hundreds of successful flights, and learned much about controlling gliders in flight. Indeed, he discovered much of what hang-glider pilots know nowadays.

Another aviation pioneer was the U.S.-born, British knight Hiram Maxim, more famous perhaps for the gun he developed. Using his giant, steam-powered, manned giant flying machine, he was the first to achieve a powered take-off, in 1894, before it crash landed.

In 1896 American Samuel Langley built a steam-driven unmanned aircraft which flew for about a minute and a half.

Ferdinand von Zeppelin, a German military man, served in the Union Army during the America Civil War. One of the bonuses of this service was that he learned about ballooning. Retiring from the army in 1891, he turned seriously to the building of large aluminum-framed airships. In July 1901 the LZ1 made its maiden flight. Over the next few years he built and flew several more. By 1909, his airships were used by the world's first airline.

In December 1903, at Kittyhawk, North Carolina, the Wright brothers *Flyer I* demonstrated manned, powered flight for the first time. They subsequently built the *Flyer II* and *Flyer III* and received their patent in 1906.

Meanwhile, since 1893, at Baddeck, Nova Scotia, Alexander Graham Bell and his associated had been studying the mechanics of flight using large, un-manned and complex kites. In 1905 one of these kites succeeded in carrying a man. In 1907 the Aerial Experimental Association was formed at Baddeck and its

Lilienthal manned glider flight

expenses underwritten by Bell's wife, Mabel. This group moved from the development of manned kites to manned, powered aircraft, culminating in the flight of the *Silver Dart* in February 1909.

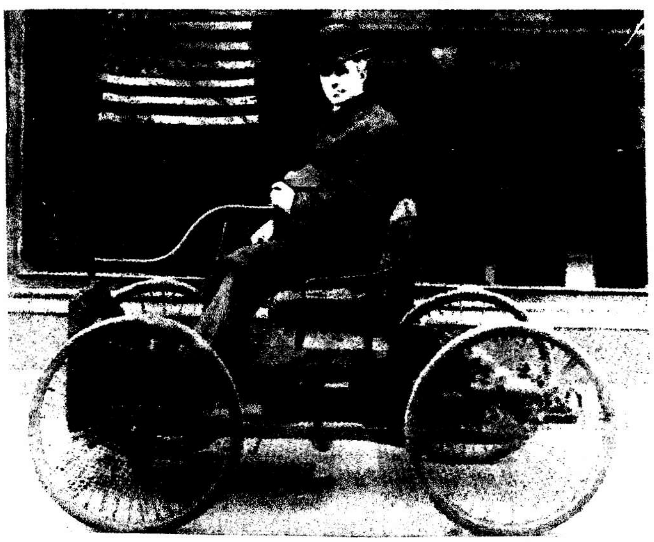
Originally, 'horseless carriages' were driven by steam, electricity and internal combustion engines. As far back as 1862, Lenoir's internal combustion engine was working inefficiently on coal gas, and Otto and Rankine were developing their theoretical gas-engine 'cycles.'

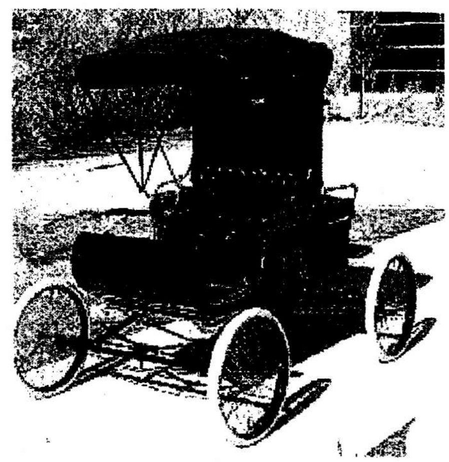
In the 1880s, electric cars appeared. Around 1885, Karl Benz and Gottfried Daimler had built small, three- and four-wheeled, gas-driven vehicles and in 1892 Gottfried Diesel patented his internal combustion engine. In the United States, by 1890, R.E. Olds had built a steam-driven car. Around 1896 the Duryea brothers built the first American 'gas buggy'- the same year that Henry Ford built his first car, the quadricycle. However, road and highway surfaces in Europe and North America had not yet been redesigned to suit the new vehicles.

The development of the automobile in Britain, however, was held up for decades by legislation, such as the 'Red Flag' laws, which required a man with a flag to precede any motorized vehicle. It should also be remembered that the railways, everywhere, fought against the automobile (and the airplane) and for many years held the monopoly for long-distance travel.

Before 1900, the Germans and French dominated the car market. Steam and electric cars were more popular than gas/diesel ones. But they also had problems which, when the gas/diesel ones were sorted out, led to their increasing popularity and eventual domination of the market. The market, generally, was encouraged by improvements to road and highway surfaces and the increasing numbers of annual motor shows and race meetings that encouraged the technical development of the vehicles.

One of the people who contributed significantly to this change was Henry Ford, who offered his first car for sale in 1903. His developing business strategy also led quite rapidly to his becoming dominant in the U.S. marketplace. R.E. Olds moved from steam to gasoline engines for his cars. One of his early successes was the 'curved-dash' Olds, which first appeared in 1901.

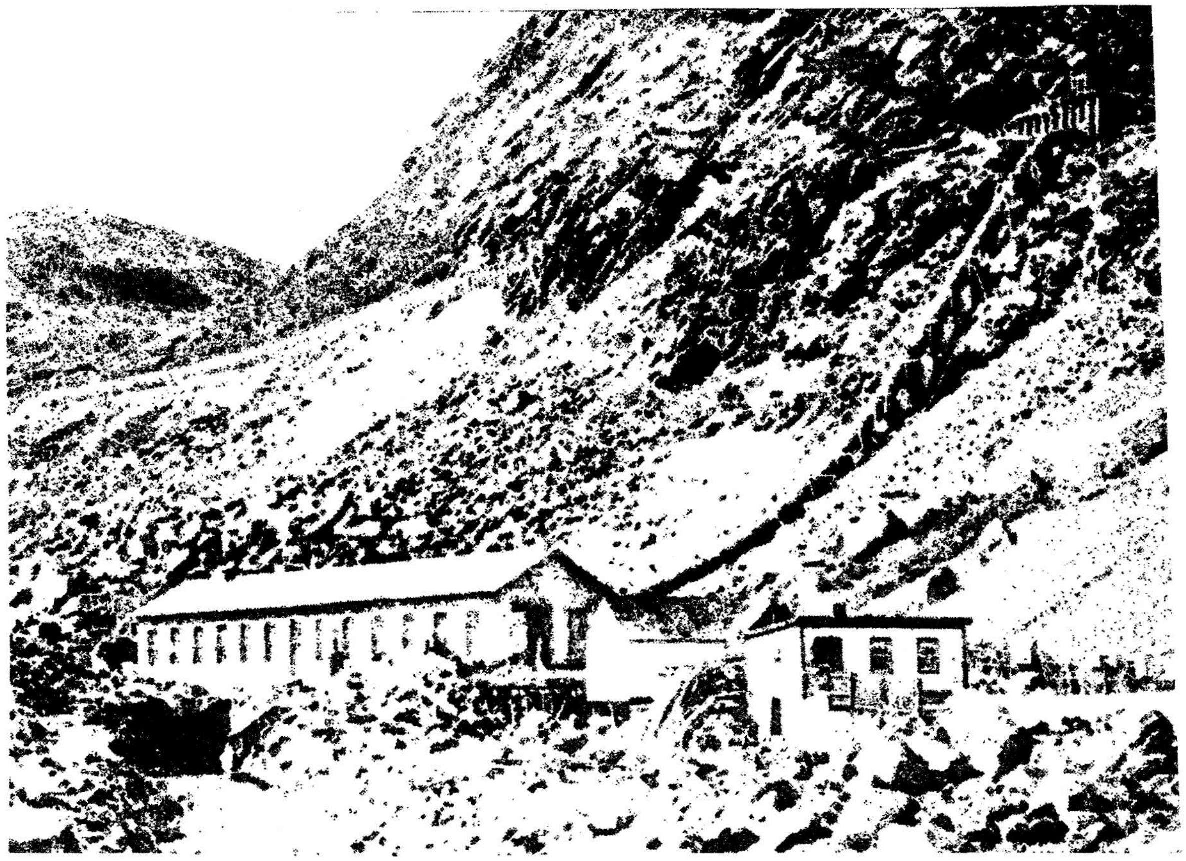

Henry Ford and his quadricycle


The curved-dash Olds

In North America, small scale water power had driven mills and other devices for decades. Steam brought with it the development of stationary power-generating systems, again on a relatively small scale. The first larger scale stationary power generation projects were private initiatives, for steel mills, for example. With the availability of D/C electrical power, distribution systems were built in 1882 at Holborn in London, England, and at Edison's Pearl Street plant in New York. However, these systems suffered from D/C's short distance transmission characteristic.

As the 20th century began, the generation of hydro-power on a large scale and in multiple plants were built at Niagara Falls, New York and Ontario, and at Shawinigan, Quebec, was made possible by the development of Tesla's AC systems and their longer distance transmission possibilities. Smaller scale hydro plants were also built for smaller markets and for those more remote from the larger ones. One of the North American examples was the Petty Harbour Power Plant near St. John's, Newfoundland, which was built between 1896 and 1900, mainly to provide power for the operation of the street railcar system in the city. Its surplus power was available for street lighting. It replaced a steam-generator plant.

The non-hydro generation of electrical, power began with steam reciprocating engines, but soon turned to the more efficient steam turbines.



The Petty Harbour Power Plant, St. John's

The turn of the 20th century was also notable for the foundation it laid for the development of nuclear engineering a half-century later. Much of the work was done at Cambridge University's Cavendish Laboratory. This early work was both theoretical and experimental, beginning with Roentgen's discovery of X-rays in 1895. In 1896, C.T.R Wilson began the development of the 'cloud chamber' as an instrument for tracking the motion of charged particles. Becquerel discovered radioactivity in 1896 and J.J. Thompson the electron in 1897. In 1899, Thompson determined the charge of the electron and Rutherford identified alpha and beta rays. Rutherford and Soddy published their paper on radioactivity and atomic integration theory in 1902 and on gamma rays in 1903. In 1905, Einstein published his general theory of relativity.

Other significant developments during this fifth landmark period included:

A significant increase in the number of skyscrapers, notably in the United States, in Chicago and New York.

The launching of some very large steel-hulled ships, the use of steam turbines to drive them, and the development of the passenger liner rivalry across the Atlantic, which improved the ships' performance.

Advances in metallurgy, such as the large-scale manufacture of aluminum, and electric-resistance welding.

The beginning by Hollerith and Burroughs of large scale information processing.

The coming of the electric street-car and street lighting; in this connection, we should not forget the contributions Thomas Ahearn made to the street car system in Ottawa.

The work of building of the Panama Canal began. It opened in 1914.

On a smaller scale, by 1901 the world's first electric typewriter, vacuum cleaner, synthetic dye and safety razor were developed. By 1904, photographs had been sent by telegraph, offset printing and the flat disc phonograph had been invented and, in 1905, safety glass was patented and the first U-boat launched.

The 1950s

In my scheme of things, the Third Industrial Revolution - the one we are presently living through - began with this sixth landmark period.

Since North America survived World War II relatively undamaged in comparison with much of Europe and some of Asia, it was the immediate breeding ground for post-war scientific and technical ideas to be exploited through engineering. In contrast, the early postwar years in Britain were difficult ones. And conflicts also arose between former allies. In the late 1940s, Churchill's famous 'Iron Curtain' descended and the Cold War began. There was the Berlin Airlift of 1948-49. The U.S. Marshall Plan was put into action and international banks were founded to help with the recovery of the rest of the world.

By 1950, China had become the Peoples' Republic. The war of note during this landmark period was the Korean War, which began in June 1950 and ended in 1953. The Suez Canal crisis erupted in the fall of 1956. However, as the 1950s progressed, generally speaking things were looking better. By 1957, for example, the Treaty of Rome had begun to bind the countries of Europe closer together. But then things started to come apart economically, when the so-called 'Eisenhower recession' began in 1958, with recovery not until the early 1960s.

The three principal elements in this sixth landmark period have, so far, been the parallel development of electronics and computers, the large-scale generation of nuclear power, and the beginning of the exploration of space using earth satellites and space probes.

The first modern computers went into operation during World War II. They had 'tubes' or 'valves' and were huge, heat-generating machines. The invention of the transistor by Shockley, Bardeen and Brittain in 1947 began the process of miniaturization in computers and other applications. Transistors were being mass produced by 1954.

As Walter Isaacson noted in his book *The Innovators*, the U.S. demand for transistors grew significantly in late 1957 due to the arrival on the market of the popular pocket radios made by Texas Instruments and the launching of the *Sputnik* satellite by the Russians, which set off the space race. These, together with the building of military ballistic missiles, stimulated the demand for both computers and transistors and helped assure that these two technologies would develop together. Computers had to be made small enough to fit a rocket's nose cone.

Among the computer-related developments of the 1950s were magnetic tape, compilers, disc storage, FORTRAN, ALGOL and COBOL and other programming languages. Kilby and Noyce independently invented the integrated circuit, or microchip, and the Digital Equipment Corporation marketed its PDP-1 computer for the science and engineering market.

Two nuclear bombs were dropped by the Allies late in World War II, inflicting enormous damage. But during the peace that followed, work on weapons continued. In the 1950s, experimental work was done on nuclear and thermonuclear weapons, and the British developed their famous 'V' bombers to carry the bombs.

However, the main emphasis in the nuclear development field was on peaceful uses, notably the generation of electrical power and the development of medical diagnostic tools. The United States, Britain, Russia and Canada were in the forefront of the power developments, although large conventional hydro, coal, oil and gas generating plants continued to be built. In 1957, the International Atomic Energy Agency was established in Vienna by 18 member countries to promote (and regulate) the peaceful uses of nuclear energy. The United States, for example, experimented with new types of reactors, the breeder beginning in 1951 and the boiling water one in 1953. In 1954 the U.S. Congress passed the Atomic Energy Act to promote the use of nuclear energy by the private sector. In 1955, the USS *Nautilus* became the world's first nuclear submarine. In 1957, the first large-scale U.S. nuclear power plant was opened at Shippingport, Pennsylvania. USS *Savannah*, the first nuclear merchant ship, was launched in 1959.

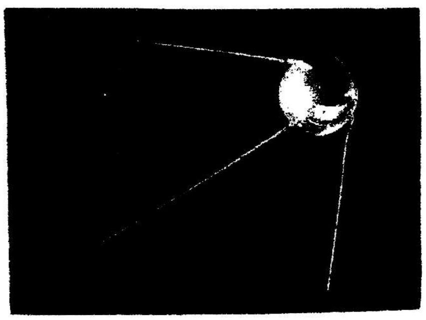
Britain established the U.K. Atomic Energy Authority in 1954 to oversee 'peaceful uses' and established a separate organization for nuclear weapons. The first British power reactor was the station at Calder Hall, which opened in 1956.

The first Russian power reactor was a 5 MW unit at Oleninsk, opened in 1954. A 100 MW unit opened later at Seversk.

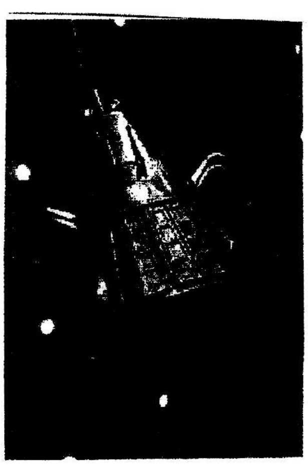
Canada's nuclear program began during the World War II at Montreal and was moved to Chalk River (CRNL) in 1946, the year after the ZEEP reactor - the first built outside the United States - started up at that site. The larger NRX research reactor followed in 1947 and the even larger NRU in 1957. Atomic Energy of Canada (AECL) took over responsibility for the Canadian program in 1952. In the late 1950s, the first stage in the design and construction of Canada's Nuclear Power Demonstration (NPD) reactor at nearby Rolphton began. Meanwhile, the main development work on the main CANDU power reactor system had been moved from Chalk River to Sheridan Park, Toronto, closer to AECL's partner, Ontario Hydro.

Chalk River: NRU reactor

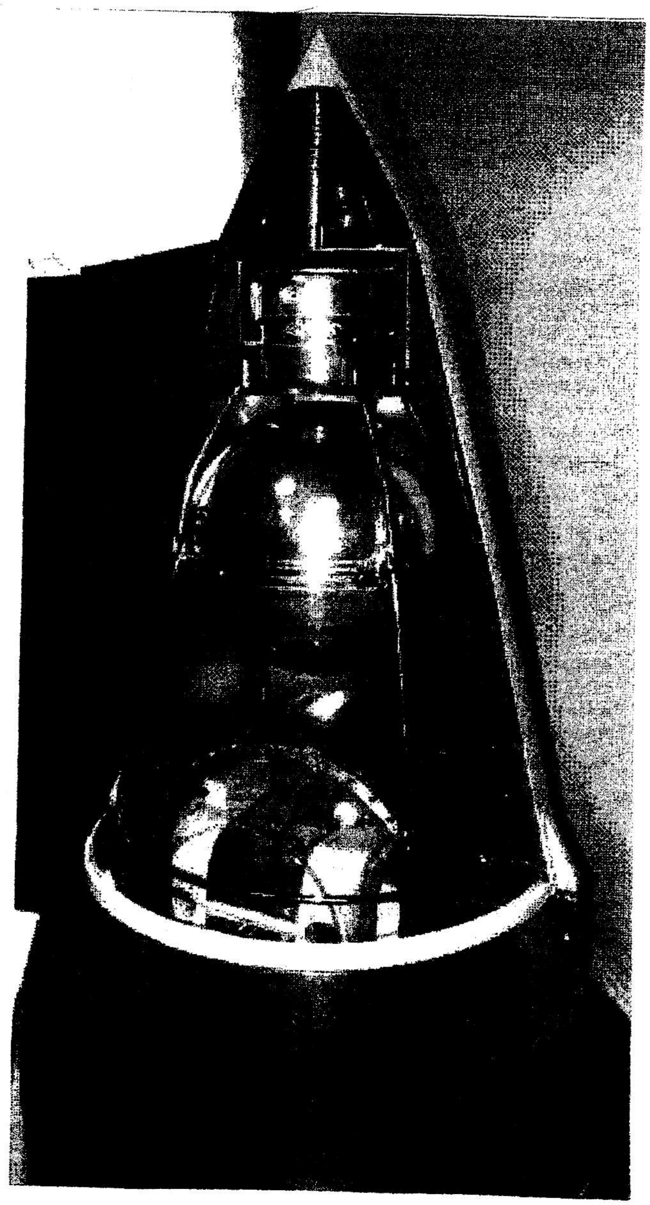
In 1955, both the United States and Russia announced their intention to launch earth satellites during the International Geophysical Year, 1957-58. In 1957, Russia launched the unmanned satellite, *Sputnik I.* A second satellite, *Sputnik II,* was launched before year-end. It carried a passenger - a dog. Their journeys were relatively short-lived. The United States began immediately to energise its space programme and the talents of German-born rocket engineer Wernher van Braun In 1958, Russia launched *Sputnik III,* a relatively much larger satellite, and the United States launched the relatively small *Explorer I* from Cape Canaveral. Both countries launched moon-probes in 1959. The U.S. *Mercury* program was launched in 1959, to be followed by the *Gemini* and *Apollo* programs, culminating in the 1969 and subsequent landings on the moon.



Sputnik I



Sputnik III



Sputnik II

In 1959, the U.S. and Canada began research into the ionosphere, which culminated in the 1960s and 1970s in the design and construction of Canadian-built 'topside-sounder' satellites - beginning with *Alouette I* in 1962 - that carried experimental instrumentation into orbit, making Canada the third country in space. The following year, the first weather satellite was launched, as was the first passive communications satellite.

Canadian space 'pioneers' included John Chapman, who led the *Alouette* project, George Klein, who developed the STEM antenna, Philip Lapp and Colin Franklin, who were involved in major technical contributions to engineering for space, and Gerald Bull, who developed guns intended to shoot instrument packages into orbit. Bull was a controversial figure and was killed in mysterious circumstances in 1990.

Chapman

Franklin

Klein

Lapp

Bull

Canada also developed the *Black Brant* missile to explore the *aurora beaurealis* from the base at Churchill, Manitoba.

The idea for an orbiting laboratory in space apparently originated during the 1950s.

Other notable engineering achievements during the 1950s included the following:

The economic growth of the 1950s, especially in North America, encouraged manufacturing, natural resource development, energy and agricultural production, increased birth and immigration rates, the growth of cities and suburbia, automobile ownership and the development of local and national transportation networks. In the United States, an Interstate Highway System was initiated in 1956. This was also the target year for the completion of the Trans-Canada Highway, but it was not in full operation for another six years.

The first off-shore oilrigs went into operation.

Military aircraft belonging to a half-dozen countries that could fly at supersonic speeds went into service in the 1950s. In 1954, the British Government established a committee to study the design and building of a civil supersonic transport aircraft, but did not build one (with France) until the late 1960s. The Russians also began work on a commercial supersonic aircraft

The aircraft industry in Canada produced the CF-100 all-weather jet fighter, the Avro *Jetliner* passenger jet and the Avro *Arrow* supersonic fighter-bomber; all three were successful as aircraft, but the *Jetliner* and the *Arrow* got no farther than the prototype stage; within the airline industry large, commercial, long-distance, piston-engined passenger and freight aircraft were replaced by jets.

Canada and the United States agreed to build a line of radar-based distant early warning stations across Canada's North; it became known as the DEW line.

Canada and the United States agreed to build the St. Lawrence Seaway, connecting the Atlantic Ocean with the Great Lakes for very large ships, and including Canada's Welland Canal; it was opened in 1959 and was one of the largest-ever international engineering projects

Television sets and programs first appeared in the 1930s, but it was not until the 1950s that regular program services were offered, instituting significant, world-wide social changes; colour TV services also began in the 1950s.

Long distance telephone dialling began in 1951 in North America.

In 1954, Charles Townes and his colleagues at Columbia University in New York developed the maser (microwave amplification by stimulated emission of radiation) which exploited high frequency oscillations to generate short-wave radio waves; six years later, the laser (light amplification...) was developed, preparing the way for fibre optics.

Several kinds of heart-regulating *pacemakers* were developed; open-heart surgery was attempted; the first artificial heart valve was implanted; and the first successful human kidney transplant was performed.

Silicones were developed for sealants, waterproofing, lubrication and surgical implants; polyethylene plastics, Dacron and polypropylene were put into use, as was float glass.

One final aside. I have stayed away from *negative* elements in each of the landmark periods. Sometimes these are obvious. Others are matters of opinion. And many have been associated with wars and other political disturbances. There have also been natural and man-made disasters, although the natural ones may lead to better warning systems and the man-made ones to better engineering.

To sum up, very briefly...

Just four points:

First, the landmark periods represent a series of *beginnings.*

Second, these periods have become shorter with the passage of time.

Third, also with the passage of time, the pace of change in the technology associated with the engineering activity has increased.

Fourth, some significant engineering achievements have been mentioned in passing for each of the periods, but there are still others that have not been mentioned for these as well as for the inter-landmark periods.

And a comment:

The Seven Wonders were among the first large engineering projects. The Renaissance fostered the widespread communication of engineering ideas as well as the discovery by Europeans of other engineering cultures in the rest of the world, and science and experiment began to influence engineering. The Smeaton-Watt years began the next two centuries of 'modern' engineering. The exhibition years saw the zenith of British engineering leadership, its decline and the start of the rise of American leadership. The turn of the 20th century gave humans the ability to use powered flight. It also provided a start to the ubiquitous automobile, highway competition for the railroads, the generation of electricity in large amounts from water sources, and the ability to process raw materials in large quantities. The 1950s began the 'ages' of nuclear power, space travel, electronics, computers and mass communications. What next?

I began with some words from Gus Kinzel's article. Let me finish with a few more. He writes:

> If you think all this is a dream, I can only tell you about a young science teacher shortly before the turn of the (20th) century. He lived with a bishop in Ohio and was telling the bishop about the wonders to come, maintaining that a person in Cleveland would soon be able to talk by telephone to someone in New York; that man would someday have automobiles that would do 35 miles an hour;

and that it was even possible that man might someday fly. Here the bishop interrupted - this was rank heresy and he would have none of it. I tell this story for a particular reason - the bishop had two sons, whose names were Wilbur and Orville.

Thank you for your attention!

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Acknowledgement

To Don Wiles, the organizer of the Almonte Lecture Series, for providing me with the opportunity to present this material to a discerning audience.

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Photographs and Illustrations

Watt engine - *Engineers* (see above), page 29

Trevithick steam locomotive - *Engineers* (see above), page 128

Pontcysyllite Aqueduct - *Engineers* (see above), page 163

Cable-laying machinery, *Great Eastern*, - *Engineers* (see above), page 233

Tesla portrait - *Tesla* (see above), front cover

Edison portrait - *Engineers* (see above), page 265

Marconi portrait – *Engineers* (see above), page 269

Lilienthal and glider - *Engineers* (see above), page 321

Original Petty Harbour power plant - Memorial University (see above), unnumbered page, photographic section

NRU reactor, Chalk River - Bothwell (see above), after page 124

Klein portrait - *George J. Klein* (see above), page 219

plus, from *Wikipedia:* the Seven Wonders of the Ancient World, the bucket and chain and the shaduf, Archimedes screw, all Renaissance photos except the aboiteau (AHW sketch), Smeaton, Watt portrait, Crystal Palace, Philadelphia Worlds Fair, Corliss engine, *Great Eastern*, Bazalgette London sewers, portraits of Brunel, Belgrand, Bazalgette and Keefer, Hamilton Waterworks, Victoria Bridge, Ford quadricycle, curved-dash Olds, *Sputniks,* Chapman, Franklin, Lapp, Bull

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