Chapter 6

The Twentieth Century

The 19th and 20th centuries form a continuity of technological and scientific development. Technology continued to develop along the path it had taken during the Industrial Revolution. Machine tools of all kinds had become available, the factory system had developed, prime movers and improved materials had been developed, and all these served as a springboard for further industrial and technological developments. The intellectual framework for the 20th century had also been laid by the end of the 19th century. All the sciences had achieved a theoretical framework that serves them to this day. Science had become firmly based on experiment and observation. Theory served to explain and relate observations and predict new phenomena to be observed and results to be obtained from further experimentation. Thus theory formed a framework for understanding and a guide to further experimentation. Any theory that was contradicted by observation would be modified or discarded. Theory could not stand on its own feet as a speculative story; it had to be firmly based on facts. In this way natural sciences became clearly separated from philosophy, theology and humanities. As this separation became established, natural science moved closer to technology until engineering and science became so interwoven that their separation is no longer entirely clear.

Physics and chemistry had reached a high degree of development and served as the scientific foundation of chemical and mechanical industries. Biology had left the era of mere description and, with Darwin and others, had joined the other natural sciences in its methods. Biology and chemistry became the main ingredients of a scientifically based medicine. With anaesthetics, antiseptics, vaccination, scientifically developed pharmaceuticals and properly established studies of anatomy, physiology, pathology and all that, medicine had joined the modern age alongside engineering. University education expanded greatly. Science became a respected occupation rather than just a pastime for gentlemen of means. Technological development no longer was the domain of talented craftsmen but joined the ranks of studies based on science. All these foundations had been laid by the end of the 19th century, and thus the way was clear for the expansion of science-based technology.

Technology had come of age and its importance was recognised by governments and the academic and industrial establishments. Before the 19th century was out, several specialist technological universities (in all but name) had been founded. Examples are the Zurich Polytechnikum[1] (1855); the Massachusetts Institute of Technology (1859); the Technische Hochschule in Berlin-Charlottenburg (1884); and the Faculty of Applied Science in the University of Liege (1893). The University of Cambridge, England, created a chair of Mechanism and Applied Mechanics in 1875 and introduced an undergraduate course in mechanical engineering (tripos) before the end of the 19th century. The French École Polytechnique goes back to the end of the 18th century and over the years has become something of an elite university. Many polytechnic schools, teaching technology somewhat below university level, though often developing into fully fledged technical universities, were founded in the 19th century in many towns and were successful in training a new generation of engineers.

Another indication of the importance assigned by governments to technology is the establishment, in the last quarter of the 19th century, of government laboratories for standards. Their task is to maintain standards in measurement, which is fundamental to modern science and technology. They have expanded beyond their original tasks and now carry out diverse research in science and technology. Examples are the US Bureau of

1 Later to become the Eidgenössische Technische Hochschule (ETH), highly respected to this day.

Standards, the UK National Physical Laboratory, and the German Pysikalisch-Technische Bundesanstalt (formerly Reichsanstalt).

The twentieth century saw momentous technological changes. To describe them all in any detail would be impossible in a single volume. Fortunately, we do not need a full description for the purpose of this book. I shall restrict myself to very brief descriptions of those technological developments that have affected society most profoundly and shall seek common trends in disparate technologies and their effects. I shall constrain the story, in the main, to the developed countries, for it is in these countries that the effects of technology are felt most directly and most immediately. The developing countries are affected less directly, though forces related to technological developments do affect the problems they struggle with. Regrettably, however, the problems of development, important and difficult as they are, fall without the scope of this narrative.

The choice of technologies to be discussed is, inevitably, an idiosyncratic one. It is very easy to point out a large number of extremely important technological developments excluded from my list and my only defence against such criticism is that it is impossible to be all-inclusive. My list is only a personal choice of examples of important technological developments to be discussed, entirely without prejudice against other technologies that might well be of equal or even greater importance. The examples I wish to discuss are, of course, chosen because they are most familiar to me. To my mind life in the twentieth century was most profoundly affected by the following technological developments:

1. Transport, including motorcars and lorries, fuel supplies and road building, fast trains, container ships, oil tankers and aeroplanes.
2. Electricity, as a pre-condition for information technology and all that, as well as because of power stations and grids, lighting, electric domestic appliances, and electric motors as prime movers in industry.
3. Information technology, including computing, communications, mass media and automation.
4. The chemical industry, particularly plastics.

Some of my omissions may surprise some readers. Notably space exploration and advances in medicine, pharmaceuticals, and food production. I regret these unavoidable omissions. As far as space exploration is concerned, I discuss the importance of near-space, i.e. satellite communications and all that it implies, but consider distant space exploration to have little economic or technological significance. Rockets do, of course, have very great military significance, but scientific exploration of distant space is merely an add-on feature of military research and is of interest to pure science only. I regard the fanciful stories about future migration of humans into outer space as pure entertainment, with no social significance. The social impact of near-space technology, on the other hand, is very great indeed, both in military and in civilian terms. Communications, weather forecasts, navigation, surveying, military intelligence and much more have been significantly advanced by the use of satellites.

We are obsessed with fame; hence we want to know the inventors of technological devices and view them as stars of technology. For the media there can be only one inventor of all important things. Reality, however, is not like that. Complex devices or systems, such as the motorcar, or television, or the computer and its components, are not invented by a single person. There inevitably is a long series of predecessors who lay the foundations for the invention, whether in terms of scientific knowledge or of predecessor technologies. The invention itself also usually has more than one progenitor. Similar ideas strike many people when the time is ripe, i.e. when the technological and scientific foundations have been laid and when social conditions are right. It is naïve to expect a complex machine or system to be invented by a single person. Not only does the same or a similar idea occur to several people at about the same time, but also each inventor needs collaborators to work out the practical details of the invention. In fact recent and current technological innovation has been happening in large teams with a leader who is a primus inter pares rather than a star. Furthermore, before the invention becomes an innovation, i.e. before it reaches the market place, a number of people become involved who are neither scientists nor engineers. They may be financial sponsors, they may be manufacturers or they may participate in the early marketing efforts. When all this is taken into account, who is to say that this or that person brought about this or that innovation? Even in the 19th century the apparent sole inventor was often not so solely responsible for the invention as is popularly assumed. Surely it is a gross oversimplification and distortion of the truth to say that James Watt invented the steam engine. He was a genius and made enormous contributions to the development of the steam engine. But even Watt had many predecessors, collaborators, sponsors, friends and advisers. And even Watt was involved in numerous patent disputes with rivals who, rightly or wrongly, claimed rights to various aspects of the development of steam engines.

Not only do we passionately seek stars to admire and worship, we like to have stars in our own country. The assignment of the title of inventor for this or that technology is often tinged with national pride. Take a relatively simple device such as the sewing machine. Ask any Frenchman and you will be told that the sewing machine was invented by Barthélemy Thimonnier in 1841 in France. Ask an American, and you will be told either that the sewing machine was invented by the American Elias Howe or by the American Isaac Merrit Singer. An Englishman might tell you that the inventor of the sewing machine was James Starley and an Austrian will claim with total conviction that the sewing machine was invented by the Austrian tailor Joseph Madersperger. No doubt there is a Russian inventor too and possibly many others.

The Automobile

The most visible and most obvious impact of 20th century technology upon modern society is that of the automobile. There are many claimants to the fame of having built the first petrol driven automobile. One of the best-supported claims is that of Carl Benz, who built a practical four-wheeled motorcar in 1893. A few years earlier, in 1885, Benz had built a three-wheeled motor vehicle with a single cylinder two-stroke petrol engine. By 1888 he was employing 50 people to manufacture the three-wheeler. Gottlieb Daimler and Wilhelm Maybach built the first high-speed internal combustion engine and mounted it on a two-wheeled vehicle in 1885, probably the first motorcycle. One year later they built a four-wheeled motorcar. However, even though most of the major inventions had been made in the closing years of the 19th century, it was the 20th century that saw the motorcar becoming a practical proposition and finding widespread application.

Before the motorcar driven by a petrol engine, several steam-driven vehicles made their appearance and, as soon as the combination of electric motor and electric battery had become practicable, some electrically driven automobiles came on the market. Among the builders of steam-driven road vehicles Amédée Ballée seems to have been one of the early successes with a series of vehicles built in the 1870s, though of course Trevithick was earlier and the principle of steam driven locomotion had by then been well established in railway locomotives. Although Telford completed his great London to Holyhead road in 1830, powered road transport was slow to take off in Britain. Whereas railways were spreading rapidly and a veritable railway fever had spread, early powered road transport spread faster in France than in England. Whereas the British were wary of the new vehicles and gave them a hard time by the legal requirement (from 1865 to 1896) that a man with a red flag should walk in front of such a vehicle to warn pedestrians and horses of the oncoming monster, the French upper classes were much more inclined toward accepting powered road vehicles than their British or German counterparts. In real terms this man with the red flag, so beloved in folklore of motoring history, had very little effect upon the development of the motorcar in Britain. At the time when development began in earnest, the law had been rescinded. Far from looking upon the motor vehicle as an object of everyday use, in its earliest days it was considered a source of fun. A plaything for the rich, which allowed them to display both wealth and manliness. Motor vehicle trials and races started in France as early as 1896 and became a regular feature that contributed much to the evolution of the motorcar.

Many early motor vehicles owed much to the technology of the modern bicycle, invented in 1885. The bicycle became extremely popular and its frame made of steel tubes, its chain-drive, and its ball bearings all proved useful in car manufacture. Thus early motor vehicles were closely related to horse-drawn carriages with bicycle technology and, of course, an engine added. Many of the early motor manufacturers were originally bicycle manufacturers, among them Opel, Peugeot, and Rover.

The logic of invention of the motorcar is easy to construct. Steam engines were the first method of converting heat into mechanical energy and motion. The locomotive was the first result of putting a steam engine on wheels and using the engine to propel the locomotive and let it pull further wagons loaded with goods or people. The rails offered the great advantage of reducing friction between the wheels and the substrate and thus reducing the power requirement. The idea of putting the steam engine on something akin to a horse-drawn carriage was a fairly obvious one and the first steam-driven automobiles started from there. They became more practical when steel tyres, used on carriage wheels, were replaced by rubber tyres, albeit solid ones at first. The next logical step was to do away with a separate boiler. Surely a more compact and more efficient engine could be designed if the heat was not produced in a separate boiler and then fed to a cylinder in the form of steam. If the combustion process could take place in the cylinder itself, driving the piston more or less directly, higher efficiency should be achieved and much space and weight could be saved. Thus the internal combustion engine was thought of and transformed into reality. The mounting of such an engine onto a bicycle, tricycle or four-wheeled vehicle was then almost a matter of course.

All the required predecessor technologies were available. Cast iron and steel of good quality and the machinery to shape these were available. Steel tubing, rubber tyres, chains, valves, tappets, and all the other technologies were in place. The only thing that was missing was market demand. The first motorcars were the clear result of a technological dream and the hope that sufficient numbers of people would be willing to share this dream. The car was a fulfilment of a technological possibility and the hope was that rich men would find the idea of riding in a motorcar, at what was seen as high speed, quite irresistible. The car was not meant for the masses, it was not meant to solve a practical problem, in fact it was not seen as an item of utility but an item of fun; a toy for the rich. And so it was for quite a long time, especially in Europe. In a very real sense this trend is being revived today, in the early years of the 21st century, when several new ultra-luxury, ultra-expensive, ultra-gas-guzzling vehicles are brought onto a market that is saturated with universally owned mass-produced cars of all shapes and sizes. The ultra-rich are getting back their toys and their means of demonstrating their wealth. The current financial crisis and environmental concerns might, hopefully, soon put an end to this madness.

It is not surprising that one of the first uses (if that is the right word) of motorcars was racing. Only the very rich and the manufacturers of motorcars could afford to participate. For the rich it was fun, for the manufacturers it was a sales gimmick and a development programme. The first automobile test was run from Paris to Rouen in 1894 and the first road race from Paris to Bordeaux in 1895. 16 petrol-driven four-wheel vehicles, 7 steam vehicles, 2 electric carriages and 2 motorcycles participated in the race. Nine cars finished within the prescribed 100 hours, one steam car and 8 petrol-driven ones. The winner was Emile Levassor, driving a Panhard-Levassor powered by a Daimler 4 horsepower engine at an average speed of 24 km/h (15mph). The brothers Michelin used the first pneumatic tyres in this race. Their car finished the race, but not within the prescribed 100 hours and not without a great deal of trouble with tyres and everything else.

The most frequently acknowledged inventor of the modern motorcar gasoline engine is Nikolaus Otto. Otto built his first internal combustion engine in 1861. In 1864 he formed a partnership with the industrialist Eugen Langen and together they built the first four-stroke gasoline engine in 1876. This engine was awarded the gold medal at the great Paris exhibition of 1876. The partnership lasted till Otto's death in 1891 and may be compared to the many years of fruitful cooperation between the industrialist Boulton and the inventor Watt. The Otto engine used the four-stroke principle first described by Alphonse Beau de Rochas and patented by him in 1862. Though Beau de Rochas first described the cycle, it has become known as the Otto cycle because it was Otto who first built a practical engine based on the four-stroke principle. Otto and Lange were commercially rather successful with their slow-running, often gas-burning, engine that replaced many a steam engine in mainly stationary uses. The firm sold 50,000 engines in the first 17 years of operation.

The theoretical foundations to de Rochas' work had been laid previously by Sadi Carnot. Carnot, an army officer and trained engineer, was disturbed by the fact that French steam engines were extremely inefficient compared to their British counterparts. He started thinking about the problem of engine efficiency in an abstract way and formulated a general theory of heat engines. He showed that the efficiency of an ideal heat engine, irrespective of the operating cycle or fluid used in it (steam, gas or an air-liquid fuel mixture), depends only on the temperature difference between the hottest and the coldest part of the engine. He designed the so-called Carnot cycle, an ideal operating cycle for an engine operating between a hot and a cold reservoir[2]. All real cycles, whether for steam engines or internal combustion engines, try to come as close as possible to the ideal

[2] The Carnot cycle consists of a reversible isothermal (constant temperature) expansion and compression and of a reversible adiabatic (constant entropy) expansion and compression.

Carnot cycle. His work came to the attention of the engineering profession through the efforts of Émile Clapeyron from about 1834.

Gottlieb Daimler and Wilhelm Maybach built the first ultimately successful high-speed petrol engine. An essential aspect of this engine was a newly designed carburettor, the device that allows liquid fuel to be mixed with air to form a gas-like compressible combustible mixture, invented by Wilhelm Maybach. Maybach's patented carburettor became widely used from 1893 and, as so many lucrative inventions, became subject to patent litigation. Daimler and Maybach formed the Daimler-Motoren-Gesellschaft for the production of automobiles in 1890. Karl Benz formed his own successful company in 1883 that built automobiles from 1885. The Benz Company merged in 1926 with the Daimler Company to form the hugely successful Daimler-Benz Company. More recently, the company has merged with Chrysler of the USA to form one of the few surviving major global motor manufacturing companies. The marriage between the two partners ended fairly quickly in divorce and Chrysler is looking for a new bride.

Another contender for the crown of inventor of the modern motorcar engine, and indeed the modern motorcar, alas a less successful one, was the Belgian Etienne Lenoir. Lenoir may lay claim to having built the first motor car with an internal combustion engine in 1862, though his vehicle was wholly unpractical and took two or three hours to cover a distance of six miles. There are many more inventors who claim to have built the first motorcar, and their claims are often supported more for nationalistic than for historic reasons. In America, for example, there are three contenders for the title of inventor of the gasoline-powered motorcar. The matter is one of indifference to me for the purposes of this book; I have no wish to act as umpire in matters of priority of inventions.

The next most important development in the design of internal combustion engines also falls into the closing years of the 19th century. Rudolf Diesel patented the design of the engine named after him in 1892 and built the first practical single cylinder four-stroke diesel engine with an output of 25hp in 1897. His design was the result of a determined attempt to design an engine that would run on a cycle as close as possible to the ideal Carnot cycle. Because of its high efficiency and, hence, frugal consumption, the engine became an immediate success for stationary, marine, locomotive and heavy vehicle applications. It took many more decades of development before it became an accepted alternative to the Otto engine, first for smaller goods vehicles and, eventually, for passenger cars. The modern Diesel engine is indeed a highly efficient engine that has captured a large segment of the automobile market. It has also become competitive with the gasoline engine in the environmental "friendliness" of its exhaust gases,albeit only in connection with particle filters that remove the carcinogenic particles of soot from the exhaust gases.

The emerging motor industry demonstrates what appears to be a fundamental law of new industries: the law of initial expansion followed by concentration. When the first motorcars were built and knowledge about them began to spread, every entrepreneur with access to basic mechanical workshop facilities started building motorcars. A bandwagon got rolling and a large number of people jumped on it. The number of car manufacturers rose rapidly during the final years of the 19th and the early years of the 20th century. Cars were hand-made individually; no standard design had emerged and the technology was readily accessible to a large number of people with some mechanical expertise. Patent protection proved entirely inadequate. Though there was much litigation about patents and even Otto lost his patent rights when a prior claim by Lenoir was upheld, it was not possible to stop people building individually designed cars and engines. By 1898 about fifty companies in America were building automobiles and this number rose to 240 in the next few years. The number soon began to decline and by about 1930 there were only three major manufacturers, five important independent manufacturers and a small number of also rans. Most of the new upstarts sank without a trace, but among the survivors are many of today's household names of motorcar manufacturers.

The initial expectations for car sales were, by modern standards, very modest indeed. The car was seen as an extremely attractive toy for the rich rather than as a universal means of transport, though the possibilities of building motorbuses and military transporters were envisaged quite early. Despite a limited vision of market openings, it was confidently expected that sales would be sufficient to keep quite a few manufacturers happy. The initial barriers to entry were not too difficult to overcome. Patent protection was weak and the required manufacturing facilities were widely available in all kinds of mechanical workshops. Those were ideal conditions for the setting up of many companies and the bandwagon got rolling. Engine manufacture was more complex and many a small maker of cars bought in engines from a much smaller number of engine manufacturers. However, with further technological developments, competition became tough and only the biggest, luckiest and most efficient players survived, while the small fish went under.

What went wrong? What does always go wrong when a technological bandwagon gets rolling? It happened with railway companies, it happened with domestic appliances, it happened with television sets and it happened with electronics and with computers. Why? There can be several causes. One is saturation. As the initial potential of the market for first time buyers is exhausted, only the replacement market remains and this may be insufficient to keep the many firms who jumped on the bandwagon in business. When every potential customer has, say, a motorcar, only the replacement market remains. This can be stimulated and kept artificially high by so-called built-in obsolescence, but it is still somewhat limited.

The saturation mechanism operates in many industries, but in the case of the motorcar industry this was not the prime reason for the death of so many companies. It took at least two generations before markets became saturated and even then the replacement market would have been sufficient to keep more manufacturing firms in business. The prime cause was the increasing efficiency and increasing complexity of manufacturing methods, which enabled fewer firms to produce more cars. In other words, even with only a handful of manufacturers left, manufacturing capacity outstripped market demand. The increased complexity of the product and associated high costs of development in a competitive market did the rest toward forcing a high concentration of firms. Whereas early motor vehicles were somehow cobbled together by skilled and imaginative individuals equipped with simple tools and standard engineering components, a modern car is the product of thousands of hours of planning, research, design, and ordering of special production machinery and special components. It requires a large firm with huge resources to finance all this outlay and to muster the qualified workforce to pull it off. Whereas the requirements for qualifications on the shop floor have decreased, requirements at the planning and design stages have increased. Unless a certain popular model is sold in very large numbers, the costs of development will not be recouped. Only luxury cars, which sell at premium prices, can be marketed profitably in small numbers.

The concentration in the industry is truly remarkable. Even the United States have only three[3] sizeable motor manufacturers; France has two, Italy has one, Britain has one rather small one, Germany has three and Japan has three or four. Most of the firms now operate on a worldwide scale. When we say that Britain has only one small motor manufacturer, this means only that there are no indigenous British owned firms manufacturing cars on any significant scale; it does not mean that motorcars are not manufactured in Britain by global firms. Ford, General Motors, Honda, Toyota, Nissan and BMW all manufacture motorcars in Britain, but Rover is the only British firm still in the business.[4] Indeed counting national firms has become largely meaningless, as most motor manufacturers are now worldwide players with factories in many countries and with complex linkages between them.

The example of the motorcar illustrates several basic general properties of technology. First, specific preconditions must be fulfilled before a particular innovation can come to fruition. The preconditions for the development of the motorcar included the development of a whole range of ancillary technologies, required both for the development of the car and its engine, and also for a wider system of transport capable of using the motorcar. This brings us to the second general property of technology: many technologies form systems. Roads had to be improved and the road network extended. When cars were first introduced onto the roads built for horse-drawn vehicles, dust and mud became major problems. All the early cars, up to about 1920, were open and their occupants had to wear goggles, leather helmets and dust-suits. As cars spread, methods of road building and surfacing were improved, e.g. by covering them with tarmac. However, as late as 1913 roads in Michigan were so deplorable that Ford could not deliver cars by road to customers living more than 100 miles from its Detroit factory.

[3] All three US carmakers are global companies based in the USA.

[4] By the time of revising this chapter in early 2009, even Rover has disappeared from the scene.

The roads invented and propagated by John McAdam in the late 18th and early 19th century consisted of a compacted and drained substrate, topped with a layer of large stones, followed by a layer of smaller stones and finished with a layer of gravel. The method was not that different from Roman methods, except that grading and transport of stones had become easier and steamrollers improved the compacting beyond recognition. McAdam roads served well for horse-drawn traffic, though even then they became alternately slimy with wet horse manure or dusty. Experiments with asphalt (a mixture of bitumen and gravel) as a surfacing material for roads or footpaths go back to the beginning of the 19th century and progressed greatly in the hands of Edward de Smedt in the late 19th century. Apparently the incentive for asphalting Paris boulevards soon after 1848 was to remove cobblestones from the reach of rioters to use as missiles or as barricades. In 1877 Pennsylvania Avenue in Washington DC became one of the first roads to be covered with the new material in the United States. The combination of the McAdam method of building roads and covering them with asphalt proved the decisive step toward modern roads, the tar mcadam, or tarmac[5] road. Apart from the need for improved road surfaces, the spread of the motorcar was dependent on an expansion of the road network. This required major civil engineering works, including the construction of bridges, viaducts, and tunnels. One of the more fortunate circumstances of the introduction of the motorcar is the fact that bitumen is a by-product of refining crude oil into petrol (gasoline). Thus crude oil serves the dual role of providing the fuel that propels cars, as well as the substrate that cars travel on.

Another major component of the motor transport system is fuel. The system consists of the exploration and drilling for oil, the setting up of a gigantic petrochemical industry which converts crude oil into motor fuel and a variety of other chemical substances, and a complex distribution system, including a dense network of filling stations that supply the millions of motor vehicles with their lifeblood. The spread of the motorcar was conditional upon the development of the network of fuel stations and vice versa. No point in buying a car if fuel is not widely available, no point in building fuel stations where there are no motor vehicles to use them. No doubt this mutual dependence slowed down the initial pace of introduction of motor vehicles. So important has the car become that the mastery over oil has become a central theme of power politics and of international conflict. Oil is, of course, also a major resource used in the manufacture of plastics and other chemicals.

The early motorcars could normally be repaired and serviced by any competent mechanical workshop, something like the latter day village blacksmith. As motor vehicles became more complex, it became necessary to establish a network of specialist car repair and servicing shops. As the number of manufacturers decreased and servicing became even more complex, with computer diagnostic devices and all that, many of the repair and service workshops became franchised and specialised for particular makes of vehicles.

Roads, fuel, workshops and dealers are by no means all that is required to operate a road transport system. We should not forget that the operation of road vehicles on public roads needs to be strictly regulated by a large body of law and regulation. Without regulation, traffic would deteriorate into utter chaos and come to a standstill. Laws and regulations need to be enforced and this means a huge apparatus of traffic police, traffic wardens, court cases, fines and so forth. As traffic is dangerous and any driver can cause or sustain very substantial damage to property or life and limb, motor vehicles have to be insured. All vehicles must carry a minimum insurance demanded by the law in order to guarantee that they are in a position to pay for any damage they might cause. Many drivers carry additional insurance to pay for damage that might be caused to their own vehicles or their occupants. As driving cars in modern traffic conditions requires a great deal of skill, a whole system of driving schools and, more importantly, examining and licensing drivers has become established. Despite all the regulations and all the driving tests, road traffic causes very large numbers of deaths and injuries. This means that a fleet of ambulances is required to ferry the victims to hospitals and hospital wards and their medical and nursing staff carry a large load of caring for victims of traffic accidents. Perhaps the word accident is a euphemism. Though undeniably some accidents do happen and may be unavoidable, the majority of so-called traffic accidents are caused by careless, unscrupulous, and aggressive use of the great power that the car puts at the effortless disposal of its driver. The car in the hands of a thoughtless driver is a potent weapon. In the early days the motorcar set out to capture the road space in more remote parts of cities and deprive children of its use as

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5 Tar is often used synonymously with bitumen

a playground. The result was carnage among children: by 1910 motorcars had killed over a thousand children in New York.[6] But still the motorcar marched on.

The motorcar is the prime example of the truly mass-produced complex product. This happened in several stages. The first stage was the production of standard components made with great precision. We have seen this happen with muskets first and the precision-made standard component became the foundation of mass production in mechanical engineering. To achieve the required precision, it was necessary to introduce accurate measuring techniques and, more importantly, accurate machine tools. It was also necessary to introduce standard screw threads and standard specifications for steel. All these preconditions had to be fulfilled before it became possible to assemble a final product from a stock of suitable interchangeable components.

Henry Ford, not content with the possibilities of simply assembling automobiles from standard parts, took the next steps toward even more efficient mass production. In today's parlance it would have been called mega production. He broke the assembly process down into very small steps and let each worker perform only a single one of these steps. Thus the division of labour was taken as far as was reasonably possible, with each worker carrying out only a small step toward the complete product. In order to speed up the process even further, the product was put on a conveyor belt that would take it past the workers, thus eliminating any wasted time between the individual steps in the production process. Each worker was supplied with the components he (or, later, also she) was to add to the assembly and was provided with the tools required for this particular task. The pace of work was dictated by the speed of the conveyor, the leeway and discretion of each worker was reduced to nothing. The workforce itself becomes a kind of machine with each part performing its allocated task. The transfer of power from workman – the blue collar worker – to engineer in the office – the white-collar worker – is complete. All flexibility, all initiative, all decision making and autonomy, and most skills are taken away from the worker and are incorporated into an engineering blueprint and detailed instructions for a small task. The assembly line was born and is alive to this day, though many operations are now performed by mechanical robots instead of by human ones.

To produce cars even more economically, Henry Ford standardised not only the working processes but also the product. The model T Ford that came on the American market in 1908, and remained in production till 1927, was sold in several body styles, but the chassis and the engine and everything else was completely standardised. More than 15 million model T cars were produced and its price was sufficiently low, and its maintenance sufficiently simple, to make it a real people's car. The model T enabled American farmers, who lived in very isolated small communities, to break out of their isolation and they bought the car in their thousands.

The Ford Company soon expanded its manufacture to Europe and European manufacturers soon introduced conveyor-belt methods to their factories. In France, mass production methods were pioneered by André-Gustave Citroën when he worked for the now defunct Mars automobile firm. In Britain, it was chiefly William Morris (later Lord Nuffield) who pioneered production methods closely similar to those of Henry Ford.

Between 1903 and 1908, before the model T and mass production methods were introduced, Ford cars cost around $1,600; a great deal more than the Oldsmobile produced by Ransom Eli Olds, that sold for between $400 to $500. By 1908 there were 24 companies building cheap cars, but Ford was not among them and continued producing cars for the wealthier customer. But soon things were to change. Henry Ford became interested in three things: vanadium steel for the production of valves; assembly line production; and so-called scientific management preached by Frederick W. Taylor Though none of these were Ford's original ideas, he applied them to entirely new problems and introduced them with greater thoroughness and greater success than anybody before him. Vanadium steel was a technical improvement and made his engines more reliable, but did not bring about a major change. The use of a production line for motorcar manufacture was revolutionary and was one of the important steps that changed the world. Henry Ford changed the perception of the purpose of motorcars. Instead of viewing the car as a toy for the rich, he looked mainly at isolated rural communities and felt that the car would help them break out of their isolation. By producing a cheap car he envisaged mass ownership and sought his profits in large numbers of cars, each sold at a modest profit instead of small numbers sold at large

6 Ruth Brandon, (2002), p. 49

profits. His formula worked out for him – he became the richest man in America – and it produced, for better or for worse, the mass ownership Ford had envisaged. Perhaps no other technology has ever had such profound effects upon society and upon individual lives.

The first Ford car to be specifically designed for mass production and built by the new methods was the revolutionary T-model. Shortly before the introduction of the T-model, Ford raised the wages of his workers and thus raised their morale and productivity. The cheapest of the three variants of the T-model cost $440; half as much as the next cheapest decent car on the market. Car production and ownership increased by leaps and bounds. The Ford workforce in the main Detroit plant – the River Rouge complex – reached 42,000 by 1924 and over 100,000 by 1929. Whereas in 1898 there was one car for every 18,000 people, by 1923 there was one car for every eight people in the USA; 13million cars altogether.

Ford believed in total control and total ownership of production. He manufactured his own steel and even went as far as owning rubber plantations. This method obviously worked for him, but was not emulated by all manufacturers and has since been almost entirely reversed. Modern car manufacturers have, in the main, become assemblers of parts produced elsewhere. For about 12 years all model T cars were black and Henry Ford is reputed to have said: "the customer can choose any colour as long as it is black". The reason for this was technical: black enamel was the only fast-drying enamel available. The situation changed when Du-Pont brought out fast drying enamels in different colours in 1924. In 1919 87% of American cars were open; in 1931 92% were closed. The change was brought about by improved methods of manufacture of pressed steel components. A closed version of the model T became available in 1925.

Financial measures contributed to the mass ownership of cars. By 1925 about 65% of cars sold in USA were paid for in instalments and by 1927 about half of the new cars sold were replacements for cars traded in as part payment.

In 1927 the model T Ford was replaced by the model A. This included many technological improvements, such as a self-starter, a new gearbox for easier gearshift, hydraulic shock absorbers, larger pneumatic tyres, a safety-glass windscreen, and rubber-insulated seat cushioning. Acceleration was much faster and the model A could maintain a cruising speed of 50mph. It sold for $495, about $100 cheaper than the rival Chevrolet. The introduction of the self-starter was a major contributing factor to the fact that more women became drivers. Thus the car did help the farmer's wife as well as the farmer to break out of their rural isolation. The starting handle required quite a lot of strength and starting early cars was an altogether tricky manoeuvre. The car had matured into an artefact that required little skill to be used and transported people with reasonable comfort at reasonable speed. A large number of further improvements separate the model A Ford from the car of the present, but no further change in fundamentals has taken place.

Once the mass-ownership of cars had become established, manufacturers became anxious to retain mass sales despite market saturation. In the immediate post-depression years General Motors, headed by Alfred Sloan, succeeded in making the car an item of fashion. A new model was produced each year, just sufficiently different from last year's model to make it desirable. A new breed of designers, mostly concerned with the external appearance of the car, gained great influence. Whereas the car had been a pure engineering product, it now became a product of the stylist as much as of the engineer. The car had developed from a symbol of wealth and a toy of the rich into a symbol of affluence and relative wealth for the not so affluent. The choice of car is influenced as much by its appearance and its image as by its practicality. Owning a sporty car reflects a sporty image upon its owner, owning the newest and most expensive car in the street bestows an aura of wealth. Owning an old, cheap, second hand car shows either the poverty or the frugality of the owner. The designer in the late thirties and the first post-second world war decades created phantasies and dreams in their attempts to sell more cars. It took the courage of Ralph Nader with his 1965 book "Unsafe at any Speed", and a generally more sceptical attitude, to bring cars at least partly back to earth and make them a little safer. The dream-car was shown to be a nightmare-car that killed its naïve owners quite unnecessarily. Governments reluctantly accepted their obligations as guardians of the public interest and introduced regulations forcing manufacturers to introduce certain safety features. Eventually safety became a selling point and at least some customers began to apply safety as a criterion for their choice of car. Although cars are now very much safer than in earlier times, they still perpetuate many follies of previous generations. Speed is still stressed and all cars can exceed legally permitted maximum speeds by huge margins. Acceleration and sporty image are still stressed by sales departments and many a modern car is more akin to a projectile than to a means of transport. The huge popularity of motor racing undoubtedly contributes to making customers susceptible to the lure of speed.

The mass ownership of cars has had the most far-reaching consequences. Congestion of cities has spread from their centres into the whole of the city. Though cars have cleansed city streets from horse droppings and the stench of urine, as was hopefully expected of them, they have substituted pollution of a more insipid and more dangerous kind. The pollution from car exhausts is one of the major factors in the much-feared greenhouse effect and many ills, from corrosion of ancient buildings to asthma, have been attributed to exhausts from motor vehicles. The car has undoubtedly contributed to the sprawl of urban areas and to the decay of many central areas. The car has caused the rise of vast shopping centres and the death of numerous small shops.

The tractor, a close relation of the car, has replaced the horse as a farm animal and thus freed much land from its use for growing animal fodder. First came the horseless carriage and the horseless plough soon followed. By 1929 there were about 826,000 tractors working on US farms and the phenomenon of overproduction of food for human consumption reared it ugly head. Whereas in cities the small shopkeeper disappeared, it was the small farmer who disappeared from the countryside. It may be argued that all human progress demands change and adaptation, but the tremendous suffering of individual families should not be overlooked. Indeed pushing change too rapidly increases the sum total of human suffering rather than the sum total of human happiness.

The production of internal combustion engines was never as simple as building early cars and was never as widely distributed among small manufacturers. Most small makers of cars bought in engines from more specialised firms. Apart from the fact that casting and machining engine blocks is no trivial matter, the design of engines required a good deal of technical and scientific knowledge; indeed it was one of the early instances when engineering became based upon scientific theory. The steam engine required some scientific knowledge; the internal combustion engine required much more and contributed to the border between science and engineering becoming rather fuzzy.

The concentration process in the motor industry is truly remarkable and demonstrates a general property of technology. When a new product becomes highly sophisticated, and its manufacture becomes both complex and specialised, most early entrants into the new field are forced to drop out. They either disappear completely or merge with other firms, so that after some time only a few large firms are left through a process of selection or by coagulation. The automobile industry in other countries fared much the same as in the USA. Some of the earliest entrants are still around, but not many. In France Louis Renault built his first automobile in 1898 and the Renault firm is still a major manufacturer. The experienced automobile engineer André Gustave Citroën was engaged in the production of munitions during World War I and formed his own car manufacturing firm Citroën Cars, in 1919. His first and many of the firm's later cars were technically highly innovative models. The firm, though merged with Peugeot since 1976, is still very much alive within Peugeot-Citroën, known as Peugeot SA since 1979. The Peugeot automobile firm, founded in 1890 by Armand Peugeot, arose out of a small family-owned workshop producing velocipedes and quadricycles. Many others have gone under, among them Delage, Delahaye, Talbot, Voisin, De Dion-Bouton, Panhard-Levassor, and Simca.

British car manufacturers fared worse than their American counterparts. The largest early British manufacturers were Morris and Austin. The Austin Motor Company was founded by Herbert Austin, later Baron Austin, in 1906. The Austin Seven model was perhaps the nearest European equivalent to the Ford T and the firm remained at the forefront of European design until its merger with Morris to form the British Motor Corporation. William Richard Morris, later Viscount Nuffield, started his entrepreneurial career with a small bicycle repair shop that also built bicycles to order. Later he also repaired motorcycles, but he and his partner went bankrupt in 1904. As all true entrepreneurs he did not give up but set up shop in Oxford and produced his first car, the Morris Oxford, in 1913. His firm prospered and went from strength to strength. Morris Motors Ltd., founded in 1919, introduced Ford production methods and expanded by various acquisitions. One of the firm's most successful small cars was the Morris Minor, designed by Alec Issigonis, which came on the market in 1948 and remained in production till 1971. The successful design of technically advanced small cars continued in the

British Motor Corporation with its most famous revolutionary small car, the Mini, now produced by BMW in Britain. Most other famous British names, such as Jaguar, Lotus, Rolls Royce and Bentley, are now in foreign ownership and many others, such as Wolseley, Lanchester, and Hillman have disappeared. On the other hand, many Japanese companies have set up shop in Britain and some US-owned global companies contribute to an active motor industry in Britain, though almost none of it is in British ownership.

The German motor industry fared rather better. Volkswagen, originally a firm founded by the Nazi regime for the production of a "people's car" (Volkswagen) was almost totally destroyed during World War II. It was revived in post-war Germany with government aid and later became a private stock company, though with a share of public ownership, and one of the largest and most successful motor manufacturers in the world. Opel, properly Adam Opel A.G., was started in the earliest days of the motorcar when in 1898 the five Opel brothers began converting the Adam Opel bicycle and sewing machine factory to motorcar production. Their first successful car came on the market in 1902 and from that date Opel went from strength to strength until 1911, when fire destroyed the factory. Opel rebuilt and used the opportunity to bring the factory up to the most modern standards. After World War I they introduced Ford methods of production. Despite this, the Opel family sold out in the 1920s to General Motors and Opel has been part of GM ever since. BMW is the most recent of German car manufacturers. Founded in 1929, it produced motorcycles and aero engines. Cars were added to its programme after World War II and became successful in the 1970s. The oldest of German carmakers is Daimler Benz, discussed earlier.

The story of the many mergers in the motor industry is a symptom of three phenomena. First, the motor industry, like many other industries, now operates on a global scale. Production is spread over many countries and marketing is worldwide. Secondly, that concentration into fewer and fewer gigantic firms is continuing, though it might possibly have reached some sort of stable state. Some observers argue that further concentration is being replaced by cooperation between rival firms on individual projects. Joint ventures between rivals may be a substitute for a further reduction in the number of independent manufacturers. A third phenomenon is the mutual share ownership. It is not uncommon for one large manufacturer to own shares in another and such shareholding may be reciprocal. The total number of global players is now a mere handful.

In the early days of the automobile it was not at all obvious which means of propulsion should be used. There were three contenders: steam engines, a combination of battery and electric motor, and the internal combustion engine. Eventually the internal combustion engine got ahead, mainly on grounds of weight and size. The battery simply was not up to the task of carrying sufficient energy at a reasonable weight and the steam engine suffered from the disadvantage that it needed a warming up period before the car was ready to start. It should be stressed, however, that so-called flash boilers could overcome this problem and that the steam engine has the advantage of not needing a gearbox as, unlike the internal combustion engine, it can develop very high torque at very low speed. The petrol engine got ahead because much more development effort was put into it, especially when the first mass producers, such as Ford, chose the petrol engine and developed the engine and the whole system associated with it. Once the petrol engine had made so much headway, the steam engine no longer had a chance of catching up. Too much had been invested into the development of the petrol engined car. At the turn of the century the outcome of the competition between steam and internal combustion was still undecided. In 1901-2 the best-selling car on the US market was a steamer and there were 50 manufacturers of steam cars around. The splendid luxurious and expensive Stanley steamer continued in production till 1927.

The development of the engine required a great deal of scientific and engineering knowledge. The choice of materials, the casting of the engine block, the choice of an operating cycle, the arrangements for adequate cooling, for ignition, for carburation and so forth were all quite tricky. Indeed the internal combustion engine marks the beginning of the era in which engineering and science became closely interwoven.

The initial stimulus for the development of the motorcar was twofold: first, the possibility was there for all to see because of the earlier development of the steam locomotive, and secondly it seemed obvious that wealthy people would love to play around with this attractive new toy. The promise of speed, the promise of control over considerable power, the possibilities of displaying wealth, manliness and modernity were temptations that ensured an adequate market for quite a few very small craft-based manufacturers.

Nobody in the early days did foresee the later enormous growth in ownership and the far-reaching consequences that the introduction of motorcars on a massive scale would have. The leap between producing cars in ones and twos, or even in hundreds, and producing millions of cars is so large that any social problems that might be caused by the car changed not simply in quantity but in quality. From very small and rather insignificant beginnings the motorcar changed into a potent mix of blessing and curse for humanity.

Whereas in the pioneering days of the motorcar one could identify a few outstanding individuals who advanced this technology, and in later years one could identify some entrepreneurs who advanced the industry, the modern enterprise is dominated by large anonymous bureaucracies, whether in engineering, in styling, in sales, or in administration. There are no more heroes – perhaps the last was Sir Alec Issigonis who became a hero when the Mini designed under his leadership achieved cult status.

We can do no more than provide a sketchy outline of the main social consequences of the introduction of the motorcar. To do full justice to the topic requires a separate book. Many have been written and some are listed in the bibliography.

The main advantage of the private motorcar is, of course, that it provides personal mobility including, for good measure, a substantial load-carrying facility. The car is supposed to get you and your luggage and your passengers from A to B at speed and in comfort. But the big cities have become so congested that travel in the car is neither fast nor comfortable. Though it protects the driver from inclement weather, it exposes him or her to a great deal of stress and frustration. And where do you park at either A or B?

The car and other motorised transport has become a major cause of air pollution with all its consequences, particularly the so-called greenhouse effect that threatens to cause highly unwelcome changes in the climate of the Earth. The car and other motorised transport have also become the major cause of urban sprawl and the geographic growth of cities.

The car has become a major cause of death and injury, as we seem unable to master the problem of road accidents. In some younger age groups, the car is the largest cause of death.

In conjunction with the refrigerator and the home freezer, the car has changed shopping habits. Car owners now shop but infrequently in large supermarkets that have displaced most small family-owned shops. The young, the disabled, the poor, and the elderly are excluded from driving and, because all life is now planned around the car, suffer severe disadvantages.

Motorised traffic has become a major consumer of energy, particularly oil. Oil is a non-renewable source of energy and our reserves are bound to run out, sooner or later. The oil industry is highly concentrated and extremely powerful and oil has become a major cause of international conflict.

Unfortunately the excessive use of the motorcar can only be curbed by shifting public investment from roads to public transport and by some suitable regulatory measures. So far, governments have not found the will or the courage to act – except by way of lip service - in the face of a strong combined lobby of the motor and allied industries and the motoring organisations. Despite its severe drawbacks, the car is still the beloved child of citizens and governments. However, using the car as a means of mass transportation is in irreconcilable conflict with its very nature as a vehicle for personal mobility. It is not enough to legislate for more frugal and safer cars, it is also necessary to find means of confining the car to use for individual transportation in situations where this can be done without too much interference with other users, and to use systems of mass transportation for mass transportation.

Aviation

We take the development of aviation as our next example of the enormous changes that the twentieth century brought about in conquering, in a sense eliminating, distance. Whereas the pedestrian can cover, say, 40km in a day; the rider or the horse-drawn carriage can cover, say, 120km. If we allow for the possibility of travel at night, a modern car can cover something like 1,600 km in 24 hours. The modern passenger aircraft, cruising at a speed of about 900km/h, and needing a refuelling stop only after about 16,000km, can theoretically cover roughly 20,000km in 24 hours, i.e. halfway round the globe at the equator. Thus, very roughly, the distance horizon of the individual has increased by a factor of 500. Perhaps more importantly, travelling by plane it is possible to reach any point on earth within 24 hours, whereas travelling on foot or on horseback it took weeks or months to reach every point on any continent, let alone in intercontinental travel in sailing ships. Air travel and telecommunications have shrunk the planet from superhuman to human dimensions. These were factors, or preconditions, for the much praised and much cursed present day globalization. On the other hand, the traveller on foot causes virtually no damage to the environment and only needs about one cubic metre of space to move in; whereas the modern aircraft needs huge amounts of fuel, produces very large quantities of highly damaging emissions, and occupies several cubic kilometres to fly at safe distances from other aircraft. We have become rather large and greedy monsters.

Modern air travel, like all technologies, had several precursors. The hot air balloon was invented by the brothers Montgolfier as early as 1783. It was constructed from paper and before the year was out, Jean-François Pilâtre de Rozier and François Laurent, Marquis d'Arlandes made the first manned flight in a balloon. Perhaps the most important and earliest pioneer of flight with heavier-than-air machines was Sir George Cayley. After some experimentation with model gliders he worked out the aerodynamic theory of aircraft wings in 1809, as well as the general layout of planes with a fuselage, wings, and tailplane with rudder and elevator. It was Cayley who designed and built the first glider to carry out a manned flight in 1853. The line of scientific predecessors to flight is even longer, for Cayley based his theory on the theory of fluid flow, established in 1738 by the Swiss mathematician Daniel Bernoulli, and on experiments by the Italian physicist Giovanni Battista Venturi. In essence, the Bernoulli theorem is a form of the law of conservation of energy. When the velocity of flow of a fluid increases because of a constriction (e.g. in a venturi tube), the pressure decreases. It follows that if air flows past a correctly designed wing, the pressure below the wing will be greater than the pressure above, thus providing lift. In the second half of the 19th century Otto Lilienthal and his followers made thousands of flights in a variety of homemade gliders. By the end of the century several kinds of balloon had flown quite extensively. Gliders and balloons may be regarded as the forerunners of powered flight, though neither of these forerunners could be flown at will from A to B and cannot therefore be regarded as proper means of transport.

The first sustained, controlled powered flight, albeit over a very short distance, was carried out in December 1903 by the brothers Wilbur and Orville Wright. They were well aware of Cayley's theory and had themselves carried out many systematic experiments. They made use of a strong headwind to provide the lift that their feeble engine failed to provide. By 1905 the Wright brothers had made some progress and managed to make circular flights of up to 24miles. Their plane was a biplane with two airscrews driven by a chain from a petrol engine. The next important pioneer of powered flight was Louis Blériot, who crossed the English Channel in July 1909 in a monoplane with a forward mounted airscrew (so-called tractor monoplane) driven by a petrol engine. A successor to Blériot's early plane was produced in fairly large numbers for a growing band of flight enthusiasts. Another successful early plane was a so-called pusher biplane built by Gabriel and Charles Voisin. One of Voisin's planes was used by Henri Farman to improve controls and other facilities and by 1909 the Voisin pusher biplane had reached something like a stable design. Louis Breguet achieved the same for the tractor biplane at the same time. These two designs dominated the next two decades, though further developments of engines and improvements of aerodynamic stability of aeroplanes continued.

It became obvious that only advances in motor design and in aerodynamic theory could improve the performance of aeroplanes. In aerodynamic theory three early pioneers stand out: F.W. Lanchester, Ludwig Prandtl and Albert Betz were the founders of this new branch of applied physics. This is another example of the increasingly close relationship between theoretical physics and mathematics on the one hand and engineering on the other.

The First World War accelerated the development of aeroplanes. It has been estimated that a total of 5,000 aeroplanes had been built by 1914 and that this number had risen to 200,000 by 1918. In the early part of World War I planes were used almost exclusively for reconnaissance. Typically they were two-seaters with speeds of 70-80mph (115-130 km/h) and a range of about 100 miles (160 km) and could fly at a height of up to 10,000 feet (3,000 m). By 1916 many of these planes were equipped with machine guns firing between the blades of the propeller, and by 1917 a specialized fighter aircraft had been developed and air-fights became common. The fighter was usually a single-seater, equipped with two machine guns, flying at speeds between 160 and 200 km/h, with a ceiling of about 6,000 m. During the later stages of trench warfare, the role of aircraft was extended to bombing, with trenches a favourite target. The Allies used mainly bomber aircraft for the purpose; the Germans used both aircraft and airships.

Aero-engines provide an interesting example of measurable technological progress. One of the characteristic figures of performance for aero-engines is the output per unit of weight; obviously we wish to obtain the greatest possible power from the least possible weight. In 1880, Otto engines weighed about 200kg/hp. In 1890, an engine designed by Daimler and Maybach weighed only 30kg/hp. It is interesting to note that the power to weight ratio of a typical petrol engine of a contemporary ordinary family car is about 1kg/hp. It is hard to know how this compares to the Daimler engine because many things, such as the clutch, may be included or excluded from one or the other figure. In 1910 the popular French Antoinette aero-engine weighed 95kg and produced 50hp (1.9kg/hp) and the Gnome, designed by Laurent Senguin in about 1914 weighed only 75kg for 50hp. In 1918 an American Liberty water-cooled V12 engine weighed only 1kg/hp.

The era of civil air transport began after World War I and did not get fully into its stride till after World War II. In the early years after World War I it seemed that the airship, a kind of rigid powered and dirigible balloon, would play an important role. Airships were built in several countries, including Britain, the US and Germany. The name of a German pioneer of the airship, Graf (count) Ferdinand Zeppelin has become a synonym for airship. He achieved 24-hour flight in 1906 and, as a consequence, obtained an order for about 100 airships for the German army that used them during World War I. The rigid airship is not the only possible powered lighter-than-air flying machine. In 1852 H. Giffard attempted to power a flexible balloon with a steam engine and others have built flexible and semi-rigid airships. With hindsight, many ideas and experiments in the history of technology look rather bizarre. After Zeppelin's death his firm continued to build rigid airships. For reasons of cost and for political reasons these were filled with hydrogen, rather than with the much safer non-inflammable helium. The first non-stop transatlantic Zeppelin flight took place in 1926. The large passenger airship *Graf Zeppelin* flew round the world and with its sistership *Hindenburg* established a regular route from Germany to the USA. Airships are comfortable and spacious in good weather, but they are very slow compared to heavier-then-air aircraft and get buffeted by the wind because of their low altitude. They also present serious problems of handling on the ground and when the *Hindenburg* burnt out on landing in the USA in 1937, the use of airships was virtually discontinued. The occasional attempt is still made to revive the airship as a cargo carrier, but so far this has not come to much. Normal aircraft and helicopters appear to fulfil all the requirements.

The development of airships was heavily subsidised by the public purse and indeed all aircraft development was carried out mostly at public expense. The military bore the brunt of the development costs of military aircraft and the costs of civil aircraft development were greatly reduced by military pioneering work.

The first purpose-built airliners of the 1920s were biplanes constructed of wood and wire, very much in the Wright tradition. Toward the end of the decade they were made of steel and duralumin.[7] Hugo Junkers was the first to build a practical all-metal plane from corrugated duralumin sheet. The skin bore part of the load; the rest was borne by struts. His firm produced a single-engine all-metal low-wing monoplane passenger aircraft in 1919, the F-13. At roughly the same time the Dutch firm Fokker produced a high wing single engine monoplane with a welded steel tube fuselage and wooden wings. In 1925 Fokker produced the first practical multi-engined aircraft, the F.VII-3m, powered by three motors and built from corrugated-duralumin sheet. Junkers were more successful with their Ju 52/3m that became the standard three-engined plane for most European airlines in the late 1920s and the 1930s. American airliners began making inroads into European markets shortly before World War II.

In 1920 the British firm Handley Page produced a 12-seater passenger aircraft that also proved influential in civil aviation. The company had been founded in 1909 by Sir Frederick Handley Page and had produced the first twin-engined bomber during World War I. Another British aircraft pioneer, Sir Geoffrey De Havilland, founded his company in 1920 and became influential in amateur club flying by producing a light two-seater, the

7 Duralumin is a strong alloy of aluminium with small additions of copper, manganese and magnesium and sometimes other metals. It was originally patented by Alfred Wilm in Germany and now exists in many variants with properties adapted to particular tasks.

Moth. The company became famous for its production of the *Mosquito,* a small all-purpose military plane, constructed mainly of plywood, that played an important role during World War II. De Havilland also produced in 1952 the very first civil jet-engine airliner, the ill-fated Comet; temporarily withdrawn after 2 years when three fatal crashes revealed a flaw in the design: metal fatigue caused a sudden fracture of a vital part of the fuselage in mid-air. Metal fatigue[8] was at that time little understood and designers had to learn from this bitter experience how to cope with it. After a painstaking investigation and a careful redesign, the Comet went back into airline service for several years. The leadership in jet-propelled passenger transport was, however, lost to Britain and transferred to the USA.

The air-cooled radial piston aero engine became standard from the late twenties. Intervals between engine overhauls were gradually lengthened from about 150 to 200 hours in the early 20s, to 400-500 hours in the 30s. Despite this and despite expensive fares, airlines were unable to cover more than about 25 to 30% of their costs and depended on government subsidies. Among the early European airlines were KLM, founded in 1920; Sabena founded in 1923; Imperial Airways (1924) and Lufthansa (1926). Some of these were formed by mergers from predecessors; all maintained their expanding networks with the aid of subsidies.

Airline services in the USA started a little later than in Europe, but by the mid-twenties expanded rapidly and by the end of the decade American airlines carried more passengers than their European counterparts.

Monocoque designs with stressed skin structures were introduced in the late twenties and early thirties and became the norm for airliners by the mid-thirties. Among the pioneers were C. Dornier, A. Rohrbach, G. Baatz and, in particular, the theoretician H. A. Wagner. Virtually all the pioneers of powered flight were academically trained engineers and progress was possible only with the elaboration of complex and accurate theories and systematic experimentation. The all-metal transport plane became standard, as did the wing without external struts, improved aerodynamic design and increased size of multi-engined aircraft.

Other important improvements were introduced in those years. Retractable landing gear greatly improved the aerodynamic performance, wing sections were improved by better understanding of aerodymamic theory, flaps to improve lift on takeoff and landing were introduced and the engines became fully cowled. Variable pitch propellers were another innovation and instrumentation expanded and improved. Operating techniques of airlines and airports improved and thus the whole business of passenger transport by air reached some form of preliminary maturity. Apart from aircraft made by Junkers, Fokker, Handley Page and other European manufacturers, the American Boeing 247 and Douglas DC2 and its successor, the DC3 (in 1935) became standard equipment of the airlines.

Unhappily much aircraft development was aimed at war. The standard bombers of World War II were four-engined planes capable of carrying large loads of deadly cargo. Fighter aircraft were also produced in very large numbers and used mainly to attack or defend bombers. The numbers produced were staggering. The US alone produced over 700,000 military aircraft during the war period. The role of aircraft in World War II, both from the strategic and the tactical points of view, would be hard to exaggerate. Some bombing raids on cities have become part of the standard repertoire of history – the almost total destruction of Coventry in England and Dresden in Germany are just two examples of the horrors of strategic bombing. The controversy on whether strategic bombing was necessary and whether it much influenced the course of the war is still a subject of debate and will probably never be unanimously resolved. Most people believe, however, that when the Germans began to lose more bombers over Britain than their factories could replace, and thus the Battle of Britain was won by the British Spitfires and Hurricanes, this represented a turning point in the war that eventually led to the allied victory.

All improvements in aircraft design from the late 20s and early 30s to this day have been the result of enormous R&D and design effort. Table 6.1 shows a few estimates for the man-hours of design engineering time invested into the various aircraft before their maiden flights. (Source: Williams, History of Technology, vol VI, fig.33.18)

8 Metal fatigue is the result of repeated stress reversal that leads, after many cycles, first to cracks on the surface of the stressed part and eventually to fracture.

Aircraft	Year	Man-hours
Spitfire	1936	300,000
DC3	1936	150,000
DC4	1942	1,000,000
Comet	1952	2,000,000
DC8	1958	10,000,000
Boeing 747	1968	30,000,000

Table 6.1 Man-hours of engineering design invested in various aircraft

These figures illustrate a fairly general law of technological development. As a technology matures, it becomes increasingly difficult to achieve further improvements. In other words, there are decreasing returns on invested effort. Any small improvement needs enormous effort to achieve. We call this fact the law of diminishing returns. Part of the design effort goes into ensuring lower operating costs. Indeed the direct operating costs of modern airliners per seat mile are considerably lower than the operating costs of earlier generations of airliners. Cruising speeds increased considerably in the early days of development, but have now stabilized at speeds just below the speed of sound. There was one single exception to this rule: Concorde. This Anglo-French airliner was built in very small numbers, flew at about twice the speed of sound, and its life as a commercial airliner finally ended in October, 2003.

Concorde[9] is not so much a civil airliner as a symbol of combined British and French national pride and engineering prowess. It is also an example of misguided government technology policy. Some aeronautical engineers at the British Royal Aircraft Establishment began looking at the feasibility of emulating supersonic military aircraft and building a civil version. As usual, a committee including aircraft industry interests and government was established and, in 1959, the committee recommended that a medium-range and a long-range supersonic airliner should be built by British industry. The estimated design costs were £50-70 million for the medium range and £90 million for the long-range plane. The idea for the medium-range design was soon dropped, but design studies for the long-range airliner began in earnest and were completed in 1961. The French manufacturer Sud Aviation announced its intention to build a SST (supersonic transport) at about the time of completion of the design study. It was also the time when the UK was beginning to show interest in joining the European Economic Community. The British and French governments agreed that talks on cooperation should begin between Sud Aviation and the leading British contender for the SST, the British Aircraft Corporation (BAC). After a year of discussions, a joint outline design emerged in September 1962. At this time the two-version plan had re-emerged and in November 1962 the two governments signed an agreement for sharing the cost of development. Britain's share was estimated at £75-80 million.

There was no demand from the airlines for such an aircraft; it was a clear case of so-called technology push. The motivation of the technologists was to attempt what had never been attempted before and thus showing their prowess. The governments involved went into it to show willingness for cooperation and to further the national prestige of French and British industry, especially vis-à-vis the United States. It was not a commercially inspired enterprise- the inspiration was technological and political. Having said that, the proponents of the scheme did try to make out a commercial case for it and produced wildly optimistic estimates for potential sales of 300 to 400 aircraft.

The medium-range aircraft was dropped again and detailed negotiations between Sud Aviation and BAC produced an agreed design in March 1964. On paper at least, Concorde was born that would be able to carry 118 passengers across the Atlantic. An existing Bristol Siddeley Olympus jet engine would be modified to produce a thrust of 32,825 lb. The project was given some urgency when American manufacturers began design studies for their own "bigger and better" SST. The commercial defeat of the Comet and VC-10 airliners by the big American jets had not been forgotten. In 1970 the American project came to an abrupt halt. Congress refused to give it the required financial support. One of the factors that influenced this decision was a growing

[9] The story of Concorde is taken from E. Braun, D. Collingridge, K. Hinton, (1979), Assessment of Technological Decisions-Case Studies, London, Butterworths

anti SST lobby that objected to the sonic boom that any aircraft creates when it goes through the sound barrier, i.e. when it exceeds the speed of sound. The objections had become very strong and it seemed unlikely that any government would permit the SST to fly at supersonic speeds over populated areas. By then environmental awareness had increased and people were worried about high fuel consumption of SSTs and damage to the ozone layer by aircraft flying at very high altitudes. Realistically, the death-knell for the project had been sounded, but those who should have listened were deaf to it.

The Anglo-French project soldiered on. The size of the aircraft was slightly increased and sales forecasts were, rather arbitrarily, increased to 500. Reality soon overtook the project. The project was completed and a technically brilliant aircraft was built and went into service in the early eighties – twenty-five years after its inception. A total of nine aircraft were sold at subsidized prices to two airlines: the national carriers of Britain and France, Air France and British Airways. The total development cost exceeded the estimate by a factor of more than ten and is thought to have been over £1,000 million. Flights in Concorde were very expensive – more than normal first class fares – because operating costs were high. Only very rich people in a great hurry used and loved this super-luxury service. Ordinary mortals fly in jumbo-jets.

After this supersonic detour we return to normal air traffic. In the immediate post World War II period the main workhorses of the airlines were former military transports, e.g. the Douglas DC3 carrying 20-30 passengers and the DC4 carrying 40-60 passengers. The DC3 was a short haul twin-engined aircraft, the DC4 was four-engined and built for longer routes. The cruising speed of these aircraft was only a little over 300km/h (200mph) and they had to fly at low altitudes because they were not pressurized.

A big step forward in long-haul airliners was made in the mid- to late fifties. Aircraft such as the Douglas DC-6 and DC-7, the Boeing Stratocruiser and the Lockheed Constellation, came into service. The successful short-haul Vickers Viscount belongs to the same period. Cruising speeds had increased to 480 – 530 km/h, the range had increased and all these aircraft were pressurized and flew at heights of about 5,000 to 6,000m, carrying about 100 passengers. So successful and popular had flying become that in 1957 more passengers crossed the Atlantic by air than by ship. This was an important crossover point and it was not many years later that regular transatlantic passenger shipping services were withdrawn altogether.

This generation of large passenger airliners was the last to use piston engines for propulsion. The piston engine was replaced by the gas turbine that operates on an entirely different principle. The air taken in is first compressed and then, in a combustion chamber, mixed with injected fuel. The expansion caused by combustion drives a turbine and this can either be used to drive a propeller – the so-called turbo-prop engine – or be expelled as a fast stream of gas that drives the aircraft by the force of reaction without further moving parts. We then speak of the turbo-jet engine. A variant of this engine uses a large fan for the air intake and allows some unmixed air to go directly into the jet, thus bypassing the turbine proper. Such engines are usually referred to as turbo-fan jets. The term jet engines covers both turbo-fan and turbo-jet engines because both propel the aircraft by a stream of gas rather than by a propeller. The propeller becomes inefficient at high speeds and generally the turbine has a higher power-to-weight ratio and is more efficient, as well as more reliable, compared to the piston-engine in aircraft applications.

The water turbine and steam turbine have been known for some considerable time and various designs of gas turbine have been proposed from time to time. In 1926 A. A. Griffith evolved a new theory of turbine blade design and in 1929 he proposed the turbo-prop engine using an axial compressor, i.e. a kind of reverse turbine to compress the air before combustion. Axial flow compressors are in universal use for all but the smallest gas turbines. A turbo-jet engine with an axial compressor was built by Metropolitan Vickers and powered a pure jet fighter aircraft that flew in 1943.

Best known as the inventor of jet propulsion in the English-speaking world is Sir Frank Whittle. He first proposed jet propulsion with a centrifugal compressor in a thesis written in the RAF College in 1928, and took out a patent on such a jet engine in 1930. Having failed to gain support from the RAF, he founded a firm Power Jets Ltd. In 1936 he built his first jet engine and tested it on the ground in 1937. With the beginning of the war the government became interested in Whittle and supported his work so that in May 1941 a Gloster fighter, equipped with a jet engine, flew on its maiden flight. The jet powered Gloster Meteor fighter soon entered RAF service and saw action during the later stages of the war.

In an independent development in Germany, Hans Pabst von Ohain, a physicist working for the aircraft manufacturer Heinkel, developed a very similar engine that was bench-tested in 1937. It first flew in the He-178 in August 1939 and an improved version was produced in 1941. The first operational German jet fighter, the Me-262 was, however, powered by a Junkers jet engine with an axial compressor developed by Anselm Franz. This jet fighter flew in 1942 and, like the British Gloster Meteor, entered active service in 1944.

We return to the post-war era and the 1950s and 1960s, when the turbo-prop and the pure jet entered service in civil airliners. Among the turbo-prop airliners the Vickers Viscount (1953) and the much larger Bristol Britannia, as well as the Lockheed Electra deserve mention. The turbo-prop era was short lived, although smaller turbo-prop aircraft are still in production and serve in various niche markets. The main airliner markets were soon captured first by the turbo-jet and then by the fan-jet.

Numerous contenders entered the jetliner market with many models of short-haul and several models of large long-haul aircraft. Standard cruising speed came near the speed of sound, 800 – 900 km/h, standard cruising altitude became 10,000 – 13,000 m and the various models of the 60s and 70s carried between 100 and 200 passengers. The development costs of the larger aircraft of the late 50s and early 60s had risen to about $300million apiece. The main contenders among the short-haul aircraft were the DC-9, Boeing 737, BAC 1-11, the BAC Trident, and the Sud Aviation Caravelle. The long haul was soon dominated by the Boeing 707 and the DC –8, although the Vickers VC-10, and the Lockheed Tristar managed to stay in the market for several years. It soon became obvious that no European manufacturer could compete with the two remaining American manufacturers: Boeing with their 707, 727 and 737 airliners and McDonnell Douglas with their DC8 and DC-9. Even Lockheed had to give up civil airliner production when the long-haul market became dominated by the jumbo-jet, the Boeing 747 and, to a much lesser extent, the McDonnell Douglas DC-10.

When it became obvious that individual European manufacturers could not survive against American competition, a consortium was formed in 1970 that became known as Airbus Industrie. Members of Airbus are Aérospatiale of France, Deutsche Airbus GmbH (fully owned by Messerschmitt-Bölkow-Blohm GmbH), each owning 37.9%; British Aerospace PLC, (since 1979) owning 20%; and Construcciones Aeronauticas SA (CASA) of Spain (since 1971) owning 4.2%. Several smaller companies participate as associates. The headquarters and main assembly plant is in Toulouse and parts are ferried from many locations, including major wing sections from Britain.

The first ever product of Airbus Industrie was the A300 short to medium-range twin-engined airliner that entered service in 1974. It was joined by a smaller medium-range plane, the A310 in 1978 and by the highly successful short/medium-haul A320 in 1987. The Airbus A-320 was first delivered to airlines in March 1988 and within ten years had accumulated orders for over 900 aircraft. It has a wingspan of 33.9m, is powered by two turbo-fan jet engines, delivering 118kN each, cruises at about 900km/h, and has a range of 5,400km carrying a typical payload. It accommodates 150 passengers in two classes, with a maximum of 179 passengers in a single class layout. There is a stretched version, the A-321 available. This has a slightly larger wingspan and slightly more thrust and can carry up to 200 passengers, and has a range of 4,260km with a typical payload. The largest Airbus model in actual service at the time of writing is the four-engined A340 with a seating capacity of up to 440 passengers and a range of 13,500km with a typical payload.

The Boeing 747, popularly known as the jumbo-jet, represents a major milestone in aircraft design and operation. It was hugely bigger than all its predecessors and it remained the dominant long-haul aircraft for the best part of 20 years. The 747 airliner was launched in 1966 and is still in production, though many technical changes have been made and many variants are available. A typical jumbo is the 747-400 that obtained its air-worthiness certificate in early 1989. The 747-400 is obtainable with a choice of several engines, at least one from each of the remaining three major aero-engine manufacturers (not counting combinations and cooperations), i.e. General Electric (USA), Pratt & Whitney (USA) and Rolls-Royce (UK). A typical engine is one of the Rolls Royce RB 211 series with 258 kN [10](58,000lb) thrust, giving a total thrust from the four engines of over 1,000kN. The plane has a wingspan of 66.44m, a total length of 70.66m, a height of 19.41m and a wing area of 524.9m^2. This

[10] KN stands for thousand Newton. Newton is the standard unit of force, defined as the force that accelerates a mass of one kilogram by one metre per second per second. 1kN is approximately 225lb.

gigantic plane can carry a maximum payload of 62,690kg and has a range of 13,180 km carrying the maximum payload. In a typical three-class layout it carries 421 passengers. The maximum cruising speed is 938km/h.

The latest and largest Airbus plane, the A380, designed to out-jumbo the jumbo, has been built and introduced to the public in early 2005. It will be manufactured in a new assembly plant in Hamburg. It is a truly enormous plane, it has two decks and two aisles and a range of 8000nautical miles (15000km). In a three class version it seats 550 passengers, in a single class it is said to be able to seat 700. It has two engine options: the Rolls Royce Trent 900 engine of 70,000lb thrust and an equivalent GEC/Pratt&Whitney engine. Many novel materials are used in the construction of this plane, such as carbon fibre reinforced plastics and a material consisting of layers of aluminium and fibreglass, known as Glare. The plane was launched in December 2000 and entered service early in 2006. There were considerable delays to early deliveries because of technical problems, but the plane is selling reasonably well and its numbers in service are growing steadily.

The largest cargo plane in the world at the time of writing is the Ukrainian Antonov AN-225. It has a wingspan of 88.4m and an overall length of 84m. It can carry a payload of up to 250,000kg, and has six turbofan engines of 230kN each. It cruises at 850km/h and has a range of only 2,500km with its maximum payload. This aircraft is designed to carry a space vehicle on its back from Moscow to Baikanour Cosmodrome. Antonov make a range of somewhat smaller freighters that are used throughout the world for carrying exceptional loads.

The commercial aircraft industry has come a long way since the early days of the Junkers corrugated flying boxes. Aircraft have become very much faster, very much larger, very much more comfortable, have a very much greater range and their operating costs per passenger mile (or kilometre) have become very much lower. All this follows the normal pattern of technological development: the quality and performance of the technology improves over time and it generally becomes easier to use. In the case of airliners this is very much the case. Navigation, aided by satellite positioning and other aids is now very simple, instrumentation and controls are all computer-aided, and autopilots have become highly effective. In the early days of transatlantic airliners there was a crew of four on the flight deck: two pilots, one engineer and one navigator. With advances in navigation aids the navigator was the first to go. With advances in aircraft controls the engineer disappeared next and now even the largest airliners have a crew of only two pilots on the flight deck Maintenance intervals have been increased and all functions are monitored by computer and faults are accurately diagnosed by computer.

What is also characteristic of technological development is the reduction in the number of competing manufacturers. After the merger between MacDonnell-Douglas and Boeing, the world aircraft industry producing large civil airliners has now shrunk to three firms. Boeing and Airbus in the Western world, and the Russian and Ukrainian industry in what used to be the Soviet world, are the only firms left. There still are several manufacturers who produce small aircraft, from the hobby-flyer to the commuter plane to the executive jet, and there are a small handful of firms that specialise in producing fighter aircraft. Concentration can hardly go much further. The main factor that has caused this extreme concentration is the complexity of modern airliners and the consequential extremely high development costs. The manufacturer needs sufficient sales to recoup development costs and this need reduces the number of viable manufacturers. The same has happened to engine manufacturers, whose number is now very small indeed, particularly in the field of large engines. The one factor that somewhat eases the situation of the aerospace industry, as it now prefers to be called, is the enormous amount of money spent by governments, especially the US Government, on defence procurement and development. But even there cooperation is the name of the game as single firms and even single governments often cannot afford the enormous development costs. On the other hand, each of the large firms buys in many components and sub-systems from specialist outside suppliers. Thus the number of firms in the aerospace industry is still substantial, but the number of suppliers of complete large aircraft is very small.

One feature of aircraft development is remarkable, though not unique: civil airliners (unlike their military counterparts) have stopped short of increasing their speed beyond the speed of sound. The speed of sound, also known as Mach 1[11], poses a real physical barrier. To go faster, everything needs to change. The shape of the most

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11 The Mach number is the ratio of the velocity of an object in a fluid to the velocity of sound in the same fluid. The velocity of sound in a gas depends upon its nature and upon the temperature and the pressure. In dry air at atmospheric pressure and 0°C the velocity of sound is approximately 330m/sec, equal to approximately 1,200km/h.

effective wing for supersonic flight is different from that for subsonic flight, the air intake for the engine needs to be different, problems of heating of the fuselage become severe, fuel consumption rises rapidly and, as soon as the aircraft flies at supersonic speed, it produces a loud so-called sonic boom. As mentioned earlier, the only supersonic civil airliner was developed for political rather than commercial reasons and the commercial industry has shied away from the problems of supersonic flight. It may come one day – who knows – but at the moment the costs and the problems are too great to justify the relatively small advantages to be gained. In fact this feature of technological development is to be found quite often. After a period of rapid development, certain features of the technology reach a stable state when very little further change occurs. Mostly this happens because a natural barrier makes further development difficult or impossible; sometimes it happens because of social barriers, sometimes simply because no worthwhile gain is expected from further development.

The speed of motorcars is an example of social barriers being hit. Most countries impose speed limits that are well below the design speeds of cars. Even when speed restrictions are largely absent, at least on motorways, as is the case in Germany, the tolerance of the public for extreme speeds is limited.

Before concluding our brief discussion of aircraft, we shall look at the specifications of a few modern fighting machines and, as in civil aviation, stand in wonder over the enormous development that has taken place since the earliest days of aviation, roughly speaking in one century.

As a first example we take the American B52 bomber made by Boeing, the oldest and one of the most awesome warplanes in the awesome US arsenal. The B52H has a length of about 49m, a wingspan of about 56m and is powered by eight Pratt&Whitney turbofan jets of about 75kN each. It carries a payload of 23,410kg and has a range of over 16,000km. Its maximum speed is 957km/h and it normally cruises at 820km/h. Modern bombers carry not only ordinary free falling bombs, but also cruise missiles and other high accuracy guided bombs. The most recent precision bombs are truly guided missiles that can hit their targets with fearful accuracy and fearful detonating power. Sometimes, unfortunately, they miss their target and hit something else with fearful detonating power. There is a miscellany of guidance systems, ranging from a computer-stored topographic map to laser beams to satellite navigation systems.

Another example of an American bomber is the supersonic Rockwell B-1B.This is a much smaller beast, with variable swept wings of only about 42m at minimum sweep and 24m at maximum sweep. The variable sweep is necessary to adapt the aircraft from subsonic to supersonic speed. It can fly at a speed up to Mach 1.25, which is 1,325km/h at high altitude. The B-1B is powered by four General Electric turbofans each rated at about 65kN, but the thrust can be increased by an afterburner to 137kN. The payload is about 13,000kg and the range with a typical weapon load about 5,500km.

Equally impressive are the figures for fighter aircraft. One of the best-known US fighters, used by many air forces all over the world, is the Lockheed Martin F-16. It is powered by a single General Electric turbofan engine producing about 129kN thrust (or a similar Pratt&Whitney engine) and has a speed of 2,120km/h at high altitude and 1470km/h at sea level. Its range is limited to about 550km, but it can be refuelled in flight from special refuelling aircraft. It is equipped with a cannon and can carry a load of various bombs and missiles. One should properly refer to these machines as fighter-bombers.

Another well-known fighter is the McDonnell Douglas F-15. This is powered by two 129kN jet engines. It has a speed of Mach 2.5 and a range of up to 4,400km. It too is armed with a gun and can carry a variety of bombs and missiles up to a maximum weight of 11,100kg.

The social consequences of flying are enormous. Large airlines now carry millions of passengers. British Airways employs 53,000 people, carries 33 million passengers per annum and links 170 cities in 80 countries with the UK. Lufthansa carries 44 million passengers per annum and links Germany with 227 destinations in 88 countries.[12] Flying has become the common mode of travel over medium or long distances. Millions of people now use a second tier of airlines, the no frills cheap operators, mostly for non-business flights. Business, government, and academic conferences have become a way of life. Everybody attends conferences at frequent intervals and airlines, conference centres and hotels make a good living. The fact that there now is so much

[12] These figures are taken from G. Endres et al., 1998, Modern Commercial Aircraft, Salamander Books, pp. 197 and 204, and may now be out of date.

interaction between firms, between governments and between Non-Governmental Organisations (NCOs) on a global scale adds to the flurry of conference travel. Technology has undoubtedly contributed to this cooperation by providing rapid global travel and instantaneous global communications.

Millions of people take holidays in distant destinations that in previous years they could not even have dreamed of and mostly did not know existed. Tourism has thus become the main industry in many countries, including countries of Southern Europe, but even in countries situated in the Pacific or the Caribbean, and it has become an important industry in almost all countries. Seaside holidays in the South are within reach of people with even modest incomes. City tourism throughout the year has become important and winter sports are now indulged in by very large numbers of people. The consequences of all this are massive hotels, seaside resorts looking like big modern cities, ski-lifts on an unprecedented scale and grave dangers to the environment in many popular destinations. Natural resources, especially water resources, are often stretched well beyond their limits. The social role of wealthy tourists in poor countries is a contentious and debatable issue.

As so many major technologies, the air transport industry forms a technological system. The aircraft is only one part of the system, albeit the very central one, and the whole system has undergone substantial technological and organisational development. The airline industry requires a vast infrastructure. It begins with the design and manufacture of aircraft and their parts and control systems. It includes the massive construction of airports and the complex operation of running airports with aircraft landing and taking off at incredibly short intervals. The airports need a ground transportation system for passengers, employees, baggage and massive supplies, including aircraft fuel. The high density of air traffic is made possible by an elaborate system of computerised air traffic control. Because aircraft have three degrees of spatial freedom – meaning that they move in three-dimensional space - they could not possibly avoid collisions without the rigid discipline enforced by air traffic control. And, unlike motorcars, even the slightest collision of flying machines leads to fatal consequences. If every aircraft flew wherever it wanted, total chaos would result. The problem of control is worse than for cars that have only two degrees of freedom, though that is quite severe enough. Because large numbers of aircraft could not possibly be controlled, the mass ownership of aircraft never became a serious proposition. In a sense, air traffic consists mostly of public transport with very few private planes thrown in for good measure. Thankfully, most of these fly at much lower altitudes from small airfields.

The motivations that caused aircraft development are illustrative of motivations for technological development in general. The early pioneers were fascinated by the dream of flying. Since the dawn of humankind humans must have felt envy for birds and their freedom from the shackles of gravity. We are tied down to earth, and we dream of being as free as the birds. The most famous of the many ancestors of this dream are the legendary Icarus and Leonardo da Vinci – one who flew but paid with his life for his presumption, the other who toiled and dreamed but never flew. The pioneers who actually flew must have been inspired by these very same dreams. As all technological pioneers they attempted to achieve what no one had achieved before, but in their case the desired achievement was a strongly felt human desire, shared by all humankind.

The second motivation (or was it the first?) was, as always, the desire for fame and fortune. The Wright brothers, for example, felt a strong urge for technological achievement, but they also were no mean businessmen and, after their initial success, went into the business of making money out of building aircraft. The same was true for all the other early, and later, entrepreneurs and their financial backers.

In the case of aircraft, the military became involved quite early on. It was obvious to any military person with imagination and foresight that here was a machine that could bestow military advantages to its users. Even the balloon was used for reconnaissance and the earliest powered aircraft were used first for reconnaissance and later for bombing or strafing enemy lines or strategic targets. For those who wish to argue that technology develops only in response to human needs, the fact that the military decided to use aircraft at an early stage provides an argument in favour of their belief. In my view, the military need came after the event. The initial motivations for the development were, to simplify the argument, curiosity, vanity, and greed. The apparent need was an afterthought; indeed it was the realisation that here was a technology that might have its practical uses. And this, I think, is the most common sequence of events. Necessity is not usually the mother of technological invention, even if the idea is tempting and sounds plausible. The question the entrepreneur asks is "what can I sell", not "what do people need". It is willingness to buy, not need, that determines the success of a product. In our rich Western societies there is little congruence between our purchases and our needs. The distinction between need and want is a theoretical one, in reality people buy goods to satisfy their wants and these include their essential needs.

Electricity

Although electricity is perhaps the most characteristic and most fundamental feature of 20th century technology and has the most far-reaching social effects, we shall introduce it in only the briefest of terms. Though lighting can be provided by other means, such as by town gas, electric power has no substitute and no equal. All manufacturing machinery is now driven by electric motors, all domestic appliances rely on electricity, all computers, radio and television rely on electricity, all water supplies and even domestic heating appliances need electric power. From razor to washing machine, from industrial robot and steel mills, from air conditioning to elevators, from whatever comes to mind to whatever comes to mind, they all need electric power. It is the ubiquitous power of our century; only mobile applications such as motorcars or aircraft rely on other forms of energy.

We start our narrative with electric lighting and with possibly the best-known inventor of all times. Thomas Alva Edison announced the carbon filament light bulb in late 1879 with a great deal of publicity. Edison had his own private industrial laboratory in Menlo Park, perhaps the first R&D laboratory dedicated specifically to technological innovation. The rate of patenting was prolific: in a single year, 1882, Edison applied for 141 patents! The work of Menlo Park included improved light bulbs, eventually substituting tungsten for carbon and thus obtaining much brighter light. It also included heavier electrical engineering, such as generators with greater efficiency, transmission of electric power and electricity meters. In the same year, the Edison Electric Illuminating Company built its first central power station in Manhattan. There was severe rivalry between gas and electricity for lighting and much of the rivalry was based on competing fears. People feared electricity because it was generated by steam engines and thus required steam boilers that might explode; gas, on the other hand, might leak and cause death by poisoning or by explosion. Eventually electricity prevailed because of greater convenience, a greater variety of applications and, last but not least, because steam boilers operating in remote power stations became perfectly safe.

Before electricity won completely, it had to go through a period of another intense rivalry, this time between direct (dc) and alternating current (ac)[13]. Edison used and advocated dc and his initial lighting installations and power stations produced dc. The original invention of dc generators and motors was made in the late 1860s by Zénobe-Théophile Gramme in France.

Till 1888 there was no alternative to dc for generating electricity and for driving electric motors. Though Lucien Gaulard and his English business partner John Gibbs started manufacturing transformers in 1883, making it possible to change ac voltage to higher or lower values with very little loss, these did not become truly useful till 1888, when Nikola Tesla, an American of Croatian origin, patented an ac generator and motor, thus removing the last obstacle to the general use of ac. The great strength of ac is the fact that its voltage can be changed so relatively easily. Hence, long distance transmission can be carried out at a high voltage. Because power W is the product of voltage V and current I, transmission at high voltage means that the current can be kept relatively low and this means that losses in transmission, proportional to the square of the current, can be kept low.

A classic case of technological and commercial rivalry unfolded when George Westinghouse bought Tesla's patent rights and his firm, the Westinghouse Electric Company, supported and manufactured ac devices. Edison strenuously opposed them. There were court battles over patent rights in the lighting field and commercial as well as scientific battles over superiority of ac or dc systems. It took many years for a decisive victory of ac to emerge. Edison himself lost much of his influence when the various Edison companies merged into the Edison General Electric Company in 1889, then merged with the Thomson-Houston Company in 1892 to become the great General Electric Company. Peace with Westinghouse was achieved in 1896 with a patent exchange agree-

[13] We speak of dc, or direct current, when both conductors retain their positive or negative polarities at all times. We speak of ac, or alternating current, when the conductors swap their polarities cyclically.

ment between the two companies. A uniform electrical system gradually emerged in the USA from the many incompatible electrical systems, both ac and dc. Before the USA settled on the 115 Volt standard, another spate of fear had to be overcome. The fear of exploding steam boilers was replaced by the fear of electrocution. It was believed that high ac voltage was particularly lethal and that the supply voltage should be kept well below a lethal level. The agreed 115 Volt for the US electricity supply emerged as a compromise between fear and economy.

In the United Kingdom the incandescent filament light bulb was invented independently by Joseph Swan in 1860, and in practically usable form around 1880, and manufactured by his company along with a variety of other electrical goods.

In 1902 there were 258 electricity-generating stations in the UK; of these 59% were municipal and 41% private. There were no standards. Some stations produced ac, some dc, and the voltage and frequency (in the case of ac) was different for each station. In 1917 there were 70 different generating authorities in London, using 50 different systems, 10 different frequencies and 20 different voltages. As electricity generation in the early stages was tied up with lighting, it was regarded as a local independent affair and nobody in the early days envisaged the enormous importance of electricity and the need for standardization.

In order to use the most powerful electric motors economically, it is necessary to produce a three-phase ac supply. This consists of one neutral conductor and three conductors each at a voltage that was later standardized to 240 Volt in relation to the neutral conductor and 380 Volt in relation to each other. The real point of the three-phase supply is that the voltage rotates and thus provides a rotating magnetic field that powers the induction motor. The first such supply was provided in London in 1900. For most large electric motors a three-phase supply is now used, the only exception being the dc motors often used for electric traction.

In 1919 Parliament passed the Electricity Supply Act that established Electricity Commissioners with the duty of "promoting, regulating and supervising the supply of electricity". The state had woken up to the importance of electricity and to the need for some form of state intervention. In 1926 a new Electricity Supply Act was passed and it was decided to establish a Central Electricity Board with the task of constructing a National Grid. Construction work started in 1927. By 1935 almost all of Britain was linked to 4600km of primary transmission lines and 1900km of secondary lines, linked to 642 electricity supply undertakings. Standardization to 3-phase 50Hz was not completed till 1947 and the voltage was standardized to 240V in 1945. The Central Electricity Generating Board was established when electricity supply came under public ownership in 1948. This lasted for about 40 years, when electricity supply and distribution came into private ownership again. The example of electricity, a typical technological system, shows clearly that state intervention is of the essence to prevent incompatibility of parts of the system and thereby greatly reducing its utility. State intervention is also vital to control the not inconsiderable hazards posed by electricity used incorrectly.

Telecommunications

Air travel has contributed a great deal to the shrinking of the world. Technology has, in a very real sense, eliminated distance. But there is another factor contributing to the elimination of distance: telecommunication. As the name implies, this is communication at a distance, instant and without restrictions owing to distance, from any point on earth to any point on earth or beyond it. Distant communication is an essential need of the military and has been tackled in various ways since time immemorial. Communication, whether at a distance or by messenger or letter or any other means is vital for many civil activities and indeed vital for the very existence of society. We need to communicate in trade of every kind, we need to communicate to promulgate laws or collect taxes or carry out any social cooperative activity. As society becomes more extensive and more complex, so the need for communication increases and speeding up the rate at which information can be transmitted offers real advantages, even though it must be said that the present emphasis on instant transmission of tremendous masses of information is largely vacuous and motivated by greed rather than by need. Technology is only interested in the mode of transmission of information, not in the content of what is being transmitted.

Hand signals must have been part of cooperative hunting and of cooperative fighting from the earliest days of humankind. Somewhat later, bonfires on hilltops or smoke signals were used to convey simple messages over great distances. Ships used hand signals or flags; armies used drums and bugles as well as hand signals. Couriers have been used since the earliest civilizations. In the 19th century, organised lines of semaphores became standard signalling practice. In France there were 3,000 miles of such lines in 1840, all operated by the War Department. In Russia, a semaphore line, consisting of towers five or six miles apart, connected St. Petersburg to Warsaw and beyond.

Early in the 19th century electricity began to be understood and it was soon realised that electrical signals could be used to transmit messages over wires. Two eminent German scientists, Wilhelm Eduard Weber and Carl Friedrich Gauss, may be regarded as inventors (albeit probably not sole inventors) of the electrical telegraph. In 1833 they used a magnet and a coil of wire and, by moving the coil in the magnetic field or by changing the magnetic field, induced an electric current in the coil (an effect discovered by Michael Faraday in 1831). This current they transmitted to the other end of town through a pair of copper wires slung over the church steeple at Göttingen. The current was detected at the other end by the movement of a magnetic needle within a coil of wire, an effect discovered in 1820 by Hans Christian Oersted. The discovery that electromagnetic signals could be produced, transmitted, and detected was of fundamental importance but did not lead directly to a practical device. The experiment by Gauss and Weber was part of extensive investigations into the properties of electricity and magnetism, pursued at that time by many scientists in many countries. This first experimental era culminated in the formulation by James Clerk Maxwell of the laws of electromagnetic fields in 1864.

The electromagnetic system of telegraphy became practical only with an agreed code for the interpretation of the signals into language. Many inventors worked on such a code and on devices for recording the messages received and many disputes over patent rights ensued. Because the purpose of patents is to grant the inventor a temporary monopoly on the use of his invention, and thus to safeguard the financial interests of the inventor, patents are often subject to litigation. In my interpretation this is further proof, if such proof is needed, that technological inventions are brought to market in order to make money. The desire for profit is the number one motivation for technological invention and innovation, even if other desires also play a role. The most successful inventor of practical telegraphy was Samuel Morse, who perfected the telegraph in the years 1832 to 1835 and finalised the Morse code – a system of dots and dashes standing for letters and numerals – in 1838. The code can, of course, be used for signalling with lights or flags or whatever, but the really significant method is electromagnetic telegraphy in which electrical signals are transmitted and recorded. The transmission was originally by wire, but with the invention of wireless transmission, wireless telegraphy became an alternative. The original Morse code proved inadequate for some languages other than English, and a European conference, convened in 1851, devised a modified code that became known as the International Morse code and is in use to the present day. The first public telegraphic message was sent in 1844 and telegraphy went from strength to strength for more than a century.

The first users of telegraphy were the railways and the newspapers. Railways needed telegraphy for operational reasons; newspapers desired it in order to speed up the spread of news. As the importance of telegraphy for the military was seen from its beginning, a debate about ownership of telegraph rights began. The solution to the ownership question varied from country to country, depending on whether more emphasis was put on private profit or on public interest.

The next step in the development of telecommunications was to add the transmission of speech to the transmission of written messages. The nature of speech as a pattern of waves carried by air became understood in about the middle of the 19th century. The science of acoustics was born and brought to a first climax by Hermann von Helmholtz, a physiologist and physicist, in his classic book of 1863. Helmholtz, a firm believer in the empirical foundation of science and opponent of purely philosophical scientific theories, began his career as a physician in the Prussian army and ended it as the first director of the Physico-Technical Institute[14] in Berlin, founded in 1888. He was thus a key figure in the emerging symbiosis between science and engineering.

Some years earlier, in 1855, Édouard-Léon Scott de Martinville had produced the phonautograph (soundwriter) consisting of a large cone with a membrane. A pig's bristle was attached to the membrane and wrote on a blackened glass that was moved along. Thus a trace of speech spoken into the cone was obtained. Though of

[14] This was a standards and research institution run by the state

no immediate practical consequence, this device must be regarded as a predecessor to the phonograph invented by Thomas Alva Edison in 1877. We may look upon the problem of transmitting speech as closely associated with the process of recording speech. What need to be done is to transform speech, i.e. acoustic vibrations, into an electrical signal, transmit this signal, and reconvert it into an acoustic signal.

Alexander Graham Bell, originally from Edinburgh, settled in Boston in 1871 as a teacher of speech and elocution, with particular emphasis on teaching deaf children to speak. He was interested in acoustic apparatus and shifted his attention to the intriguing possibility of telephony. In 1876 he patented a device for the transmission of an undulatory electric current, now generally regarded as the basic invention of the telephone. An almost simultaneous patent application for a similar device by Elisha Gray led to a prolonged and bitter battle over priority of the invention and rights to exploit it. The circuit described in Bell's first patent is somewhat weird and wonderful. Apparently the electrical signal was to be modulated by immersion of a metal wire in mercury, thus altering the resistance of the circuit. In a second patent, of 1877, the circuit consists of a small magnet attached to a membrane and moving in a wire coil, thus inducing a current in the coil that follows the movement of the membrane. The receiver is simply the reverse of the transmitter: the modulated current in the coil causes the magnet and membrane to move. Attaching the coil to the membrane and leaving the magnet stationary can achieve the same effects. In Bell's arrangement the transmitter and the receiver were identical. The principle of the moving magnet is one possible design for a transmitter, though modern telephone transmitters (microphones) are based on a patent filed by Edison in 1878, using the fact that the resistance of carbon powder can be modified by pressure. If a capsule is filled with carbon granules and is closed by a membrane, the moving membrane modifies the resistance, and thus the current in a suitable circuit. This type of microphone went into production in 1895 and has been widely used. In this case the receiver, based on the principle of the moving coil or magnet, is different from the transmitter. In modern parlance we would say that the telephone is an analogue device because the current induced in the microphone closely follows the movement of the membrane. In other words, the current is analogous to the pattern of mechanical movement caused by the air-pressure waves of speech.

As far as the private citizen is concerned, the telephone falls into the category of want that might be called the "would it not be nice if" want. Nobody needed the telephone, but the thought of being able to speak to friends and family at a distance is a nice thought. For business users, the utility of the telephone was far more obvious. There were real benefits to be had from the ability to speak to managers located in different locations of the same company, or to suppliers, or to customers. At a time when companies grew and began to spread their operations to different locations, the telephone was useful to such an extent that it might be classed as a real need or, more accurately, as a factor that determined the way businesses operated. Whether it increased their efficiency or not is a moot point. Undoubtedly they would have found modes of operation without the telephone, but the telephone did shape the corporations to a certain extent and for corporations operating in this particular mode, the telephone became indispensable. Major technologies used in organisations have a great influence on their modes of operation. Bell foresaw the possibility that business organisations might see benefits in the telephone and he and his associates and financial backers aimed the telephone specifically at the business market. The private market came much later, as a kind of afterthought.

Though eventually Bell came through with flying colours, he was involved in lawsuits for many years. The most difficult battles were fought against Elisha Gray who filed a patent for the telephone only hours later than Bell. The dispute was finally settled when the National Bell Company (Bell's company) appointed Western Electric (Gray's company) as its equipment manufacturer. Indeed Western Electric remained the manufacturing arm of Bell till long after the latter had become AT&T.

The first small manual telephone exchange, serving five banks, was installed in Boston in the spring of 1877. The total number of telephone users in New York reached 778 in the same year, including several stockbrokers. In 1889 Almon Strowger invented a mechanical switching device that was first introduced in 1892. The automatic telephone exchange, at first using the Strowger switch, spread widely when the rotary dial was added to telephones from 1896 and, in standard form, from 1910. From these small beginnings both telephony and telegraphy went from strength to strength. It was telegraphy that managed to span the oceans first by laying submarine telegraph cables.

The Transatlantic Cable[15]

News travelled slowly across the oceans, as it was limited by the speed of ships. As telegraphy spread within Europe and America and other continents, the idea of laying cables across narrow stretches of water within the continents naturally presented itself. Indeed the first cable connecting England and France was laid in 1851 and in the following few years England became connected to Holland and Ireland, and Italy became connected to Corsica and Sardinia. Telegraphy had become important to newspapers as well as to civil government and the military. It helped to control far-flung government, business, and military operations.

In 1854 the wealthy American Cyrus Field decided to organise the laying of a telegraph cable across the Atlantic Ocean, essentially connecting Europe with the USA. Field's wholesale paper business could manage perfectly well without him and did not provide the challenges that Field desired. He was a man with a penchant for heroic deeds and there was nothing heroic about selling paper and printing supplies. He was also a man fond of unusual business enterprises.

Field contacted a number of people that he thought might be helpful, mainly wealthy potential investors in the enterprise, but also experts in oceanography and telegraphy. Morse, one of the latter group, promised his support and the oceanographers assured Field that conditions on the route from Ireland to Newfoundland were favourable, with the ocean bed reasonably smooth and flat, and the depth between 1500 to 2000 fathoms (approximately 2700 to 3600 metres). The investors also proved interested and Field founded the New York, Newfoundland and London Telegraph Company and raised a capital of $1.5 million. This was obviously a business enterprise. The aim of the investors was to make a profit, and this meant that they were keenly interested in the success of the enterprise. None of them were technically educated, but all of them appreciated the business benefits this technological enterprise might bestow upon business in general and their own business in particular. To most of the investors the transatlantic cable was an investment opportunity like any other; for Cyrus Field it became a passion.

The first step was to construct a line between New York and Newfoundland. The Governor and Assembly of Newfoundland granted the company a charter and gave it considerable financial support in the hope of bringing business and employment to Newfoundland. The line was duly constructed, but it took a whole year and devoured a third of the company's total capital. Part of the line had to be laid over rugged terrain and one stretch of 85miles had to cross the sea. After an initial failure, this stretch of submarine cable was manufactured and laid successfully by a British company, using the steamer Propontis.

Cyrus Field was the untiring driving force behind the enterprise and made numerous trips to England to raise political, financial and technical support for the project. In 1856 he founded a second company in Britain, the Atlantic Telegraph Company. The company obtained its charter and a promise of generous help from the British Government. With a huge empire to govern, it was very much in the British interest to obtain rapid and reliable communications with its far-flung territories. Good communications would be helpful to the administration, to business and, last but not least, to the military. Although the USA was not yet a world power with global interests, extensive lobbying by Cyrus Field and his friends extracted a matching promise of support from the American Government.

Both British and American naval vessels surveyed the proposed route for the cable and conditions were again found to be favourable to the enterprise. The actual design of the cable proved to be rather controversial. Every known authority on matters of electricity, especially matters of the propagation of signals in an insulated cable operating under water, was consulted, but the advice was not unanimous. The eminent physicist William Thomson, the later Lord Kelvin, and others advocated as thick a copper wire as practicable in order to reduce resistance to a minimum. The equally eminent Michael Faraday advocated a thin cable in order to reduce capacitance. The fact of the matter was that the problem was not fully understood and that even concepts such as resistance and capacitance were somewhat vague. The board of directors of the company, faced with contradictory scientific advice, did the obvious thing and chose the thin cable because it was a lot cheaper.

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15 This description is based almost entirely on the fascinating book by John Steele Gordon, 2002, A Thread Across the Ocean, Simon & Schuster.

The cable was duly manufactured. It consisted of seven strands of thin copper twisted together. The insulation consisted of three layers of gutta-percha[16] followed by a layer of hemp saturated with tar, oil and wax. Finally, the cable was armoured with iron wires twisted round it and coated with another layer of tar to protect the wire from corrosion. Thomson tested the cable and found that the copper was not nearly as pure and as homogeneous as he had wished. The total length of cable of 2,500 nautical miles (4,600km) weighed 1 ton per mile. This made it too heavy to load on any existing ship and thus had to be loaded in two halves on two ships. The two ships chosen were the USS Niagara and the HMS Agamemnon. It took 30 men three weeks to load the cables and the two ships set out with a naval escort in the summer of 1857. The cable broke when about 400 miles had been payed out because the paying out machinery was inadequate to the task and a mechanic had failed to release its brake when the ship rose on a wave. Thus 400 miles of cable were lost and the attempt was abandoned, to be restarted in the following year.

A new chief engineer was appointed, a William Everett, on leave from the US Navy, and new paying out machinery was built to his design. The design has stood the test of time and has survived, virtually unchanged, to the present day. The cable was frequently tested by sending a Morse signal from one end and picking it up with a sensitive galvanometer, specially designed by William Thomson, at the other end. The second attempt at laying the cable was started in mid-Atlantic, with the two ships sailing in opposite directions. The attempt was fraught with difficulties. The ships encountered a most terrific storm and the cable broke a few times, but could be spliced again with only short lengths lost. Eventually the cable snapped and a new attempt (the third) was restarted in July of the same year, 1858. This time the cable was laid successfully from end to end. To celebrate the occasion, Queen Victoria and President Buchanan exchanged messages on 16.August. The truth was, however, that the cable worked very poorly. Signals were weak and transmission slow and after a few weeks the cable went dead altogether.

Cyrus Field was a man of great perseverance, bordering on sheer obstinacy. He managed to get a Commission of Enquiry appointed that was to look into the causes of the failure of the three attempts to lay the transatlantic cable. Leading scientists, including Sir Charles Wheatstone and Sir William Cooke, joint holders of a telegraph patent of 1843, participated in the enquiry and made numerous recommendations. One of the results of their recommendations was the proper definition of concepts and units, such as the watt, volt, ohm, ampere and more. They also recommended that the cable be properly tested before and during the laying operation.

Another unrelated and independent technological development proved crucial to the eventual success of the transatlantic cable. Isambard Kingdom Brunel had completed his – by the standards of the time – gigantic and revolutionary steamship - the Great Eastern. It was launched in January 1858 (after a previous failed attempt) and had had a rather lack-lustre career. She was too big and too advanced for her time and several owners had tried in vain to make money by using her as a passenger and cargo ship. Brunel died during her sea trials, but not before having drawn Field's attention to the possibility of using her as a cable-laying ship.

Field went about the difficult business of raising more money for another attempt at laying the elusive transatlantic cable. By 1864 he had secured sufficient finance and sufficient political support to be ready for another attempt. A new cable, much heavier than the previous one, was designed by the physicist William Thomson and the engineer Charles Bright. It was manufactured by a new company, formed by mergers, the Telegraph Construction and Maintenance Company. Many improvements had been made. Apart from the wire having a greater cross-section, the copper it was made of was purer. Both these measures reduced the resistance of the cable. The insulation consisted of four layers of gutta-percha supplemented by a new insulating substance, Chatterton's compound, between the layers and over the wire. Then came a layer of hemp soaked in pitch and finally an external armour made of good quality steel wire, coated with hemp. The cable was tested at every stage and completed at the end of May, 1865. Field was now the only American involved in the enterprise, all other participants, and most of the capital, were British. Only one journalist, William Howard Russell of the

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[16] Gutta-percha is obtained from a tree native to Malaya and is similar to rubber, but not as elastic. It is thermoplastic and sets to a hard but somewhat flexible insulating substance. Some years earlier Werner von Siemens had constructed a machine for coating wire with gutta-percha, thus producing cables.

Times, was on board when the Great Eastern set sail on 23rd July from Ireland on its transatlantic voyage. This was the fourth attempt.

It was not all smooth sailing. Some bits of wire were found stuck in the insulation, shorting the cable. At one stage the cable had to be retrieved from the ocean bed to repair a fault. Finally, the cable snapped, disappeared into the ocean and was not found again till a year later. Most men would have given up, but not Cyrus Field.

A new company, the Anglo-American Telegraph Company was formed and a new cable was manufactured. This time the outer armour was made of zinc-coated steel, thus preventing corrosion. The outermost layer of hemp was not soaked in pitch and was not sticky, as its predecessors had been. The new expedition left Ireland for Newfoundland on 13. July, 1866. This time all went smoothly and the end of the cable arrived in Newfoundland a fortnight later, on 27. July, 1866. The cable that had been lost previously was raised from the ocean and laid successfully, as a second cable, in September, 1866.

Cyrus Field died in 1892, having been involved in several other exciting business projects. The traffic density on the cable was initially low, because prices were exorbitant. One of the results of this initial pricing policy was the formation of United Press International, which allowed newspapers to share the cost of transatlantic dispatches. Eventually prices dropped and traffic increased. The operation was profitable throughout and the laying of submarine cables became fashionable. By 1900 there was a total of 15 transatlantic cables in operation, as well as a cable from Suez to Bombay. Australia was reached in 1871 via Singapore, and China and Japan followed. In 1902 a line from Vancouver to Australia and New Zealand completed the cable-girdle round the globe.

In 1914 the British Navy successfully cut submarine cables connecting Germany to the world and thus forced the Germans to use wireless communications during World War I, thus becoming more susceptible to having messages intercepted.

The original submarine cables proved suitable for telegraph communication, but not for telephony. The rate of transmission was too slow for that. Submarine cables with so-called repeaters, or regenerators, i.e. amplifiers that regenerated the signal at intervals along the cable, were first introduced in 1956. Cables were then capable of carrying 33 simultaneous telephone calls. This figure rose to many thousands, and even hundreds of thousands over the following decades, especially with the introduction of fibre-optic cables. Despite current competition from wireless and satellite connections, much telephony is still carried by cable, though the major signal carrier is now an optical fibre carrying light pulses rather than a copper wire carrying electrical pulses. The numbers of international calls made annually from the USA has risen at a staggering rate: In 1950 it was one million; in 1997 it was 4.2 billion calls.

The meteoric rise of telephony began when Bell started introducing automatic exchanges (central offices) on a major scale immediately after the First World War, in 1919. But it was the universal introduction of direct dialling, with every subscriber in the world able to dial every other subscriber without human intervention, that spread rapidly in the post World War II period, and particularly in the 1970s, that made the telephone an instrument of global communications. With rising prosperity in the same period the telephone became ubiquitous and, in the Western World at least, ownership of telephones is now almost universal.

We are ahead of ourselves and have to return to the early days of telegraphy and telephony. It followed from Maxwell's theory that electromagnetic phenomena should spread through space much like waves spread in water. In other words, an oscillating electric charge with its associated magnetic field, i.e. an electromagnetic field, spreads from its point of origin as a wave. The predicted phenomenon was experimentally confirmed by Heinrich Hertz in a series of experiments conducted in the years 1885 to 1889. Hertz also demonstrated that light consisted of electromagnetic waves. The difference between radio waves and light or heat waves is merely in their respective wavelengths.

The Russian Aleksandr Popov was one of the first to transmit and receive electromagnetic radiation, radio waves, over some distance and built a primitive radio transmitter and receiver in 1895. In Russia he is considered to be the inventor of radio communications.

In the West, the same role is assigned to Guglielmo Marconi, who experimented with radio waves and filed a patent for radio telegraphy in 1896. The two inventors did not know about each other. The transmitter consisted of a high voltage spark that was controlled by a Morse key. The receiver consisted of a weird device known as a coherer, perfected earlier by Sir Oliver Lodge. The coherer consisted of a glass tube with two electrodes, filled with loose iron filings. Normally the tube does not conduct electricity because the filings are packed too loosely. In the presence of an electromagnetic wave the filings cohere (as shown in 1890 by Édouard Branly) and render the tube conducting. If the tube is part of an electric circuit, a current will be recorded. If the tube is immediately struck by what was called a trembler, the filings become loose again. In this way the coherer can be used to detect electromagnetic waves and was indeed used by Marconi for this purpose. Lodge and Muirhead had transmitted and received an electromagnetic signal over a short distance in 1889, merely for the purpose of demonstrating electromagnetic waves. Marconi was not interested in demonstrating a scientific fact – he was after the practical possibility of signalling over a distance without using a wire. For obvious reasons, both Marconi and Popov aroused the interest of their respective navies. Marconi improved the performance of his apparatus greatly by adding an aerial and in December 1901 managed to transmit a signal from Newfoundland to Cornwall. The spark gap as transmitter and the coherer as receiver were crude devices, just sufficient for the transmission of Morse code. Great improvement in the range of broadcasting was achieved by implementing an invention by the German physicist Ferdinand Braun of a novel antenna circuit linked to the transmitter circuit by induction, patented in 1899. The 1909 Nobel Prize in physics was awarded jointly to Marconi and Braun for their invention of radiotelegraphy.

Though Marconi achieved some commercial success with these devices, he filed another patent in 1900 in which he introduced the possibility of transmission at predetermined wavelengths. Marconi's second patent was based on previous work by Oliver Lodge, Nikola Tesla and others and was eventually overturned by the US Supreme Court. However, the principle was established that a tuned circuit – tuned with the aid of variable inductance and capacitance –could be used to determine the wavelength of a broadcast radio signal. The tuned circuit has remained a crucial element of radio communication.

For the transmission of complex information by radio waves, we now use a so-called carrier wave that is modulated – either in amplitude or in frequency – by the signal to be transmitted. The receiver is tuned to the wavelength of the carrier wave and detects the signal carried on the wave. The detector – essentially a rectifier – was invented and improved during the half century following Marconi's initial success. Different types of rectifier, based on different physical phenomena, have been used.

The first type of rectifier is based on the vacuum diode invented in 1904 by Sir John Ambrose Fleming. The principle is simple. If we take a light bulb, consisting of a hot filament in an evacuated glass envelope, add a second unheated electrode, and apply a voltage between the heated electrode (the cathode) and the cold electrode (the anode) current will flow only if the anode is positive and the cathode negative. If we apply an alternating current, only that part of the current will flow through for which these conditions are fulfilled, thus the alternating current will be converted to direct current, we say that the valve rectifies the ac current. The reason is that the heated cathode emits electrons, carrying a negative charge that can be attracted to the anode, whereas the anode does not emit electrons. If a high frequency current is received in a circuit containing a rectifier, only the dc component will flow through and this can be measured by an instrument such as a galvanometer, or it can drive a suitable receiver.

In 1906 Lee de Forest inserted a grid, a second electrode that allowed the passage of electrons through it, between cathode and anode. A voltage applied to the grid could greatly influence the current flow through this triode valve, (initially called Audion by its inventor) and the valve could thus act as both rectifier and amplifier. In the following years vacuum valves (vacuum tubes in American parlance) with further grids were invented, the tetrode, the penthode, and so forth. Whereas Fleming was an academic scientist, de Forest was a scientist/businessman and was determined to be seen as the father of radio. A fierce battle over the priority of invention between them is an unfortunate characteristic of invention and innovation. When money and/or fame can be made from priority of inventions, protagonists are bound to fight over priorities, especially as inventions of a closely similar character often occur at roughly the same time. Once the preconditions of knowledge and technology are established, fertile minds attempt to take the next logical step of development and thus bunching and simultaneity of inventions can easily occur.

The various inventions of valves, of fixed and variable capacitances, inductances, resistors and transformers, not to mention aerials, made the broadcasting radio a practical proposition. A whole new branch of engineering, electronic engineering, developed during the next half century, based entirely on these types of active and passive circuit elements. Radio was one practical result, a variety of amplifiers and servomechanisms became possible and, eventually, early computers and television resulted. In the second half of the 20th century electronic engineering turned mostly away from thermionic valves and replaced them by solid-state electronics. The transistor, invented in 1947, and the silicon integrated circuit led to an enormous diversification and expansion of electronic engineering.

In the early days of radio, with Lee de Forest one of the leading lights, radio broadcasts became established. Perhaps the most important contributor to this development was David Sarnoff who worked his way up from messenger boy to radiotelegraph operator and achieved his first bit of fame when he picked up the distress signals from the sinking *Titanic*. He was soon promoted within the Marconi company and began to promote the idea of broadcasting entertainment on radio and marketing a radio receiver. In 1921 he was manager of the newly formed RCA (Radio Corporation of America). The broadcasting of the commentary on a heavyweight-boxing match proved tremendously popular and RCA sold radio receivers in very large numbers. In 1926 Sarnoff founded the NBC (National Broadcasting Company) and thus completed the establishment of radio as a popular means of receiving news, other information and entertainment. Radio has never looked back. By stressing the role of one man, however important, we do an injustice to the many other people involved in as large an enterprise as the establishment of broadcasting. But even a detailed history cannot do justice to every contributor, and this is only a short sketch, far short of a detailed history.

The same apology has to be made when we come to the subject of television. A very large number of inventors described a variety of methods that might be used to broadcast moving pictures. The Russian scientist Boris Rosing described and built a prototype of a television receiver using a cathode ray tube, invented in 1897 by Ferdinand Braun. In 1907 he managed to send and receive crude pictures and may thus be regarded as one of the successful pioneers of television. Vladimir Zworykin, a Russian-born American engineer, is often regarded as the main inventor of modern television, though he is by no means the only contender. Zworykin became a researcher in the Westinghouse Electric Corporation in 1920. In 1923 he patented a television transmitter tube and in the following year a receiver tube. In 1929 he demonstrated an improved system and moved to RCA as head of electronic research. In the following years Zworykin and his team made further improvements in both black&white and colour television. Research into television was active outside the US as well. In Germany Baron Manfred von Ardenne demonstrated a television system in 1931. In Britain, John Logie Baird demonstrated a partly mechanical television system as early as 1925 and a research group at EMI, led by Isaac Shoenberg, produced its own fully electronic system in 1931. It had become clear that the definition of mechanically scanned systems was necessarily inferior to that of fully electronic systems. Modern television was the child of many parents; virtually all of them members of research groups in industrial laboratories. The period of systematic industrial R&D had come into full swing.

World War II delayed the spread of television, but it regained momentum rapidly in the post-war period. Television-broadcasting organisations were set up in most countries and the number of programme channels increased. When the market for black&white receivers became saturated, colour television was introduced and thus flagging sales were revived with a better and more expensive product. Commercial broadcasting was introduced in many countries – following the American lead – and competition between the many channels led to ever lower quality standards. Zworykin himself, the leading progenitor of television, in later life lamented the way television had been used to trivialize subjects instead of for the educational and cultural enrichment of audiences. There can be little doubt that in this particular field competition leads to declining standards by tending toward the lowest common cultural denominator. In the search for mass audiences, anything that titillates or entertains at the least demanding level is welcome. Violence has become part of the daily fare of TV. There can be little doubt – even if some pundits do doubt it – that the routine constant showing of violence on television leads to imitation of violent behaviour among the uneducated young. To them, violence appears to be a normal pattern of behaviour rather than the uncivilized aberration that it is. Indeed the role models that television presents are often pathetic and lamentable rather than worthy of imitation. Some programmes on some channels are, of course, excellent. Some news, some discussions, some drama, some nature films and some science programmes are true enrichments for their viewers. But most television is harmless trash at best and dangerous rubbish at worst.

The spread of television has extremely far-reaching social consequences. The majority of people throughout the world spend a large proportion of their leisure time watching television. Sitting in front of the goggle box has largely replaced other forms of social life, including conversation within the family and casual visits by friends. Television is a window on the world and, because of its poor quality, it provides a very limited and distorted view of this world, especially as it is infiltrated by insidious propaganda. It has also led to the growth of the personality cult, a wholly deplorable cult in view of the fact that the cult figures are not usually worthy of admiration or imitation. The stars of today's television world glitter, but their glitter is not that of diamonds but of glass beads. Television has often been hailed as an instrument of democracy. It was thought that an informed public would be able to make informed choices in their voting behaviour and in their political activities. Instead, the public is as ill informed as ever and politicians are reduced to sound bites that are meaningless but memorable. Unfortunately, sound bites are no substitute for information or argument, and photogenic politicians are no substitute for thoughtful, wise and honest leaders. Most discussions are too brief and too lacking in discipline to be meaningful and often deteriorate into slanging matches. Despite all slogans on political independence, political patronage has proved too powerful and inconvenient views are rarely aired. Television influences public taste to a considerable extent. Unfortunately, it mostly goes for the garish and vulgar rather than for good quality stylish design.

Television has contributed to enormous growth in the entertainment and advertising industries. It has grown far beyond its predecessor and contemporary industries, such as film, radio and the press. Growth in the entertainment industry was an inevitable consequence of reduced working hours and increased leisure time. In itself, this is not a bad thing provided the entertainment is of good quality rather than vacuous pulp. The growth in advertising is a much more dubious proposition because it educates us to become consumers, it projects to us a make-believe world in which truth is irrelevant, and it attempts to make us dissatisfied with our lot, whatever that lot might be. To be happy, we have to buy, whether we need it or not. I think that advertising has induced a very cavalier attitude to truth and value in many of us.

The television industry has again reached a stage when the market for television receivers is saturated. Everybody has a colour television set. A new device is urgently needed that will revive the fortunes of the industry and will induce people to part with their money. It was thought that High Definition TV would provide the answer, but now the industry seems to have settled on digital TV instead and we shall soon all be buying digital sets or, at least, digital boxes to convert our existing sets to digital reception. The ultimate cry will be digital high definition TV using, of course, large flat screens rather than bulky cathode ray tubes. In return, we are promised better technical quality and more programmes. Will that make us happy?

Computing

The branch of electronics that has most influenced modern life, apart from radio and television, is computing. The predecessors to electronic computers are mechanical calculating machines of all kinds. Perhaps the most famous, though almost certainly not the most influential, of these machines is the analytical engine conceived by the English mathematician Charles Babbage. Babbage proposed two calculating machines: the "difference engine" and, in about1834, the "universal analytic engine". The latter was to perform any arithmetical operation, was to receive instructions on punched cards, was to be able to store numbers, and had sequential control. Thus the engine was to contain many elements of modern computers. Neither engine was ever completed in Babbage's lifetime. The Swede Georg Scheutz completed the difference engine in 1844, with an improved version in 1855. The machine was used for a few years to calculate actuarial tables for the British Registrar General. In 1991 some British scientists built Difference Engine No 2 on the basis of Babbage's notebooks. Babbage was a professor of mathematics at Cambridge University and pursued his ideas, with some government aid, for academic reasons; though it is likely that he, as most academics, always kept an eye on possible practical applications for the satisfaction of their pride and for possible financial gain. Babbage's engines, however, must be viewed as curiosities of no practical consequence.

There are many more predecessor mechanical calculating devices, some associated with illustrious names, such as Leibniz and Pascal. Of much greater practical importance were the various mechanical calculating machines that began to appear on the market in the closing years of the 19th century. The first key-operated calculator was demonstrated in 1887 and in 1893 William Burroughs added a paper roll and a printing mechanism to such a calculator. He founded the Burroughs Adding Machine Corporation in 1905 that eventually, in 1986, became part of the Unisys Corporation. For the analysis of the 1890 census in the USA the statistician Herman Hollerith designed a calculating machine that used inputs from punched cards, similar to those used by Joseph-Marie Jacquard in 1804 for the control of a weaving loom. Hollerith became the founder of the Tabulating Machine Company in 1896, which later became the International Business Machine Corporation (IBM). Mechanical or electro-mechanical calculating machines of all shapes, sizes and capabilities became firmly established in the administrative offices of commercial firms and in public administration and remained essential tools until they were displaced by digital electronic calculators and computers.[17]

A variety of miscellaneous electronic or electro-mechanical computing devices were built in several industrial research laboratories that might all be viewed as predecessors to the modern digital computer. These efforts began in the late thirties and continued into the forties. Serious large-scale computer projects also started in the 1940s in both USA and England. Two of the earliest electronic digital computers were built by John Atanasoff, later joined by Clifford Berry, at Iowa State College between 1937 and 1942. At Bell Laboratories George Stibitz used relays to build simple digital computers between 1937 and 1940. In Germany, Konrad Zuse built a series of computers in the years 1936 to 1949 that used electromechanical relays. The relays fulfilled the same function as the valves or transistors of later devices: they acted as binary switches with one position denoting a 0 and the other position the 1.

Atanasoff's ideas proved greatly influential and important for the most ambitious and best known of these early efforts, the ENIAC (Electronic Numerical Integrator and Computer), started in the University of Pennsylvania in the spring of 1943 and officially launched in early 1946. The project was supported by the US army in the hope that the machine would assist in new calculations of ballistic tables. The leading scientists involved in the project were John Mauchly, Herman Goldstine and J. Prosper Eckert Jr. The machine used more than 17,000 thermionic valves and was of enormous size. It is difficult to assess how urgent the task of calculating ballistic tables was, but there can be no doubt that some sort of military demand for the machine existed.

A more obvious and urgent demand existed in Britain for the specialist electronic calculating machine, the Colossus. The machine was specifically designed to help with the de-coding of German teleprinter messages in a system code-named Fish. Colossus, though designed for a specific task, had many features of a universal computer. It became operational in February, 1944 and made no small contribution to the cracking of German codes and thus to the British war effort. Colossus was just about the right name for it, for it used 1,500 vacuum tubes and must have consumed huge amounts of electricity. An enhanced version, Colossus II, used 2,400 vacuum tubes and became operational in June 1944. Colossus was built in Bletchley Park, an almost legendary wartime intelligence research centre. The popular fame of Bletchley, however, rests upon its successful de-coding of German messages using the Enigma coding device.[18] The best-known figures associated with Bletchley were Alan Turing, T. H. Flowers and Max Newman.

A milestone in the consolidation of computer design was The First Draft of a Report on an Electronic Discrete Variable Automatic Computer (EDVAC), written by the famous mathematician John von Neumann in June 1945. The report was partly based on the ideas developed by the team at the University of Pennsylvania in connection with ENIAC and a machine that was to follow it. This report, although in name a first draft, was widely circulated and discussed. In effect it laid the foundations to the design of modern digital computers. A further report on stored programme computers by von Neumann, in association with Herman Goldstine and Arthur Burks, further strengthened the foundations of computer design.

A flurry of activity followed the first computer efforts, initially driven almost entirely by cold-war military needs. The design of the hydrogen bomb required great computational effort and the growing activity of designing and building a variety of guided missiles involved no mean computational effort. In 1948 Nicholas Metropolis built a computer at Los Alamos Laboratory, following the von Neumann design. Jay Forrester built

17 Much information on the history of the computer was gleaned from Brian Winston, 1998, Media Technology and Society, Routledge.

18 I am much indebted to Peter Wolstenholme for putting me right on Colossus, referring to the Official History of British Intelligence in the Second World War (F. H. Hinsley et al.)

a similar machine at MIT. Princeton University completed a computer in 1952 that was used in the final design stages of the hydrogen bomb.

IBM began in earnest to build computers. One went to Northrop for guided missile work and almost all the others were used for military work. The only exception was one computer delivered to the US Weather Bureau.

In the late forties and early fifties it was still thought that a very small number of computers would satisfy all the foreseeable needs, mostly of a military nature. Only in the later fifties did it dawn on people that the computer could be more than a tool for the design of military hardware or ballistic tables or weather forecasts, and that it could perform useful tasks in commercial or state administration and in civil research.

Universities, in collaboration with the military or with commercial firms supplying the military, remained involved in computer design in the immediate post-war period. In Britain, a research group including Thomas Kilburn and Frederic Williams was active at Manchester University, designing the Ferranti Mark I computer. At Cambridge University, the EDSAC (Electronic Delay Storage Automatic Calculator) was built in 1949 under the leadership of Maurice Wilkes. The National Physical Laboratory (NPL) was designated to cater for computer needs at the national level in Britain. The NPL recruited the mathematician Alan Turing, of Bletchley fame, to help with computer design. Turing started building a machine, but it apparently was not completed and he left for Manchester and died soon after the move. NPL built a smaller version of Turing's design in 1950, called Pilot Ace. English Electric built the machine commercially under the name Deuce.

In USA, the National Bureau of Standards also became involved in computers and built the SEAC in 1950, which remained in operation till 1964. This machine used the newly developed solid-state diodes combined with thermionic amplifier tubes. This was the beginning of a synergetic relationship between the nascent semiconductor and computer industries. It did not come to full fruition, however, till the 1970s.

The rise of the semiconductor industry will not be described here; the interested reader is referred to an earlier book[19]. The development of the computer industry will be described, albeit with extreme brevity. The Transistor and the later Integrated Circuit devices offer two tremendous advantages over thermionic valves: they consume very little power and are extremely reliable. They are also extremely compact and the modern computer simply could not have happened without them. Thermionic valves are too bulky, consume too much power and are too unreliable. The marriage between semiconductor devices and computers was made in heaven.

Eckert and Mauchly founded their own computer firm and built their first UNIVAC machine for the US Bureau of Census in 1951. The firm was taken over by Remington-Rand and continued to build a range of UNIVAC computers. Initially most sales were made to the military, but gradually commercial firms became equally important customers.

In 1953 IBM brought its 701 computer onto the market. The IBM marketing strategy was to lease the machines, rather than sell them. In 1953-54, 17 such computers were leased to military agencies or aircraft manufacturers.

In the late sixties integrated circuits began to replace transistors in computers. Among the first computers using integrated circuits were the CDC 6600, built by Control Data Corporation, and the IBM 360 series. These machines proved highly successful.

It has been estimated that by 1965 there were 31,000 large mainframe computers in use in the world. But smaller computers were soon to make most of the running. First there was a range of what might be termed intermediate computers, produced by the Digital Equipment Corporation, founded in 1957 by Ken Olsen. Their first PDP (Programmed Data Processor) machines came on the market in 1960. In 1963 the PDP 8, a machine using transistors instead of valves, proved highly popular on the market. It cost $18,000, which was cheap for a computer at the time, and was the size of a filing cabinet, which was compact at the time. This was only the beginning. Prices and sizes dropped rapidly with the introduction of integrated circuits and so-called mini-computers that cost as little as $8,000 in 1969. By 1971 there were seventy-five firms making mini-computers.

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19 Ernest Braun and Stuart Macdonald, 1982, Revolution in Miniature, 2nd ed., Cambridge University Press.

In the early 1970s IBM replaced the 360 series by the 370 series, in which both the logic circuits and the memory consisted of integrated circuits (ICs). The IC memory constituted a major breakthrough, replacing as it did a variety of more or less clumsy memory devices, such as magnetic drums.

The era of the personal computer, also variously known as desktop-, home-, or micro-computer, was yet to come. Two of the pioneers of these now so ubiquitous machines were Steve Wozniak and Steve Jobs who designed and built the Apple I computer in makeshift facilities in 1975. It used an IC central processing unit (CPU) that cost only $20 and 4kbytes of random access memory (4k RAM). The product was a little rough and sold at $666 only to enthusiasts. Some 175 units were sold in 1976. Early in 1978 they raised some capital and built a more sophisticated unit, the Apple II. By the end of 1980, Apple had become a public stock company valued at $1.2 billion! In 1981 IBM jumped on the bandwagon and brought out its own Personal Computer. They sold 35,000 of them in the first year of production and by 1982 there were just under a million computers in American homes. Ten years later it was 31 million. Several manufacturers came and went and the market settled down to the IBM PC that was now assembled from readily available components by a large number of so-called no-name firms. It was almost like the automobile in the early days, except that the PC's, unlike early automobiles, were all almost identical and were assembled from standard components supplied by the electronics industry. By the end of the century there were still some no-name computers available and many computer dealers assembled machines to personal requirements, but the market was dominated by a few large manufacturers such as Hewlett Packard, IBM, Apple, Dell, Compaq, Fujitsu Siemens, and several more.[20]By 2009 the desk top computer and its even more compact equivalent, the notebook, have become ubiquitous. The usual process of concentration of manufacturers has taken place; there are not many left. On the other hand, a large number of computer service people assemble computers to order from standard components readily available on the market.

Prices have not really come down much over the years; instead specifications have gone up by leaps and bounds. The perfectly ordinary computer I am writing this on has specifications that early mainframe computers could not even have dreamed of. A microprocessor that operates at a rate of 750 MHz, 64 MB RAM, 20 GB hard drive, DVD ROM, CD reader-writer, 56 kbit modem[21], and a whole lot of software, not to mention a printer and a flat-bed scanner. As almost all private users, I need only a fraction of these capabilities. Indeed many owners of home computers use them for games and/or as sophisticated typewriters only. Some use a spreadsheet, a database, graphics and e-mail and some further Internet facilities. What most people would like, and cannot get, is reliability – crashes are all too frequent – and freedom from vicious virus attacks. In general, one suspects that most of these machines stand idle for much of the time and many users are irritated by the unpleasant habit of the machines to do automatically what nobody had asked them to do. They display a kind of wilfulness considered helpful by the pogrammers and irritating by the users. Unfortunately the home computer, despite its undoubted advantages, has brought its own problems of crime. Computer crime is of two kinds: either involving plain fraud or theft; or the misuse of chat-rooms, especially those used by children. The Internet has proved a willing and able carrier of advertising, most of it unwanted by the user. Much to the outrage of the moralist, it has also proved a useful medium for pornography. On the other hand, there is quite a lot of useful information on the Internet and this is used by private citizens, business, and students at all levels, though it is not as easy to use as the less skilled user would like. Some of the demand for personal computers is driven by schools and their students.

In 1980, the IBM PC needed an operating system. By some chance coincidences, the choice of system supplier fell upon the small firm Microsoft, founded by the young entrepreneurial software wizard Bill Gates. By 1986 Microsoft had become a public company and by the end of the century Microsoft had become a giant company. Bill Gates had become one of the richest men in the world and a succession of lawsuits, alleging abuse of a monopoly position, dogged Microsoft. New versions of operating systems were introduced at frequent in-

20 Apologies to the manufacturers not named here. I am sure they will understand that the names given are just examples chosen at random.

21 By the time of final revision of the text, in early 2009, many of the above specifications have become obsolete. I now use a notebook with much better specifications and a broadband connection to the Internet. And I still am nowhere near using all this sophistication.

tervals and numerous customers complained about system faults. Instead of gradually ironing out the faults, new versions with new faults succeeded each other in rapid succession. It is easy to see that this policy makes commercial sense, but it is equally easy to see that it is irritating to the customer. New systems mean new sales, the painstaking improvement of old systems brings customer satisfaction. Commercial firms rate sales more highly than satisfaction. The customer can, theoretically, choose a different system. In reality, however, the very fact that such a vast majority of operating systems is of the Microsoft PC type makes a change very difficult because of compatibility problems and because of problems of availability of application programmes compatible with other systems. Whether Microsoft is guilty of monopoly machinations or not, the Microsoft systems have a de-facto monopoly position with only a small band of enthusiasts choosing Apple computers, with their own system, instead.

This is all I have to say about stand-alone computers. The rest of the computer story belongs to networking. It all began in the USA with classified military and national security computer nets in the 1970s. In 1983 a distinct military computer net, the MILNET, became established that later merged into the Defence Data Network. At about the same time university computer departments established their own net, the Computer Science Research Network. In 1985 the National Science Foundation (NSF) agreed to build and manage a net connecting its own five main computer centres, the NSFNET. The NSF agreed that their network could be used by commercial users for on-line computer services. In a parallel development, the commercial firm CompuServe, part-owned by Time Warner, started its own network that by 1994 had grown into a huge enterprise with 3.2 million subscribers in 120 countries. Tim Berners-Lee, a computer scientist working for the European Nuclear Research Centre in Geneva (CERN) created protocols for the World-Wide-Web that opened for business in 1992. The NSF withdrew and WWW became a purely commercial enterprise in 1995. Of the many services provided by the net, e-mail is proving the most successful. The almost instant transmission of informal written messages is proving vastly popular. The Internet has become fashionable; most people would not be seen without it. Almost all firms and government departments have web sites. Whether it is for better or for worse, or whether it makes little real difference, who is to say? The fact is that the Internet is not very secure and that its users have great difficulty maintaining the integrity of their systems and their transactions.

The very advances of the personal computer have displaced the mainframe computer to applications where very large amounts of data have to be manipulated. Large government or private administrative offices or large technical or scientific users need mainframe computers; others use personal computers on every desk, networked so that they can cooperate and the network of small machines replaces a larger one. For some highly specialized applications, such as weather forecasting or design of complex engineering systems, so-called super-computers are now used. These are very expensive machines made by very few manufacturers and used in a few specialist centres. The super-computer can save a lot of trial and error experiments in engineering design with mathematical simulation substituting for physical experiments. Design work and technical drawing are now almost invariably computer-aided. This saves a lot of time in producing engineering drawings and it also enables designers in different locations to cooperate on a design by linking their computers.

The home computer has not caused a social revolution. I agree with Brian Winston when he says: "The gap between the hype of revolution and the reality of the underused, complex and extremely expensive consumer durable sitting in millions of middle-class Western homes grew wider."[22] Writing on a computer instead of a typewriter increases the number of revisions and corrections; though whether the quality of the texts increases in proportion must be doubted. The availability of encyclopaedias and dictionaries and many other informative programmes is helpful; the availability of violent addictive computer games is not. Many computer enthusiasts predicted that working from home would reduce employment in offices significantly, to the point that rush-hour traffic in cities would decrease noticeably. No such thing has happened; cities have become even more congested despite the fact that some administrative and professional work is now carried out from home. The impact is not massive, because the amount of such work is not massive. The need for social coherence among colleagues and the need for consultation and supervision are too great for the office to be replaced by a network of lonely people sitting in front of their computer screens. Home shopping, home banking and booking of

[22] Brian Winstone, (1998). Media Technology and Society. London: Routledge, p.238

travel or entertainment over the Internet are perhaps significant, but so far they have not amounted to a revolution, even though it has become difficult to book a cheap airline ticket other than on the internet. For one thing, financial and commercial operations are held back by fear of fraud. For another, people like to deal with real people rather than with awkward-to-use inflexible web sites and they like to handle real goods rather than just see pictures on a screen. People also like to ask their own questions, rather than be fed on a diet of "the most frequently asked questions". No doubt the use of home computers will continue to spread, but many people will be frustrated by the dumb machines replacing real people. For the new generation, however, computers and their mode of transactions are becoming the norm.

The impact of computers on the world of work and on the economy is quite another matter. The Internet is certainly an important contributing factor in the globalisation of the economy. Though it is true that large international firms had their own communications networks even before the Internet, it is nevertheless true that by linking everybody to everybody the global economic network has become more universal and more effective. Administrative procedures have changed beyond recognition. Whereas in the past any change in taxation was a laborious and lengthy process, now governments can easily implement such changes and do so with great frequency – for better or for worse. Other administrative procedures have become automated and impersonal and mistakes, though rare, are not easily spotted or rectified. Telephone information systems are now all on computer and a customer seeking information on almost anything is frustrated by long waits at so-called call centres. Often he/she is confronted by the electronic voice of a computer only, and it takes an even longer wait to reach a human operator. Once reached, the operator knows only what he or she can read off the screen of the computer sitting in front of him/her. The operator has little knowledge and less flexibility. To reach a human with some knowledge and the discretion to be flexible is quite difficult. To reach the person you wish to speak to is often impossible. The computer can only answer questions anticipated by the programmer and, generally speaking, these are not the questions you wish to ask.

It was expected that computers would increase productivity by leaps and bounds. Whether they have actually done so is a moot point. First, the productivity of an administration is impossible to measure because the expected outputs are not quantifiable and can be varied at will. The effort involved in the calculation of a payroll may be quantifiable, but the aftercare of customers, or the services provided for the community, are not. Frantic efforts are often made by governments and managers to quantify the unquantifiable, but all that these efforts lead to is distortion, fraud, and misinformation. In manufacturing the computer probably has increased efficiency by streamlining and optimizing production lines and by linking production to sales. As the name implies, the computer plays an important role in computer-aided design. But industrial efficiency in the wealthy countries is extremely high anyway and industrial products are, consequently, relatively cheap. What the wealthy countries need is cheaper and better service and repair provisions for their industrial goods in order to get away from the environmentally and socially damaging throwaway attitudes. What these societies also need is better provision for public health-care, for care for the elderly, and support for the underprivileged. What societies need is better crime prevention and better prevention of drug abuse and all the other social ills of so-called post-industrial societies. And they need better education in the fullest sense of the word. In all these tasks the computer may have its role to play but it cannot replace humans who think and feel for themselves.

We have discussed several of the defining technologies of the 20th century: automobiles, aircraft, electricity, telecommunications and computers. It is obviously impossible to cover all technologies that characterize the 20th century – there are so many of them. All we can do is mention one or two more and try to summarize what all these technologies have in common and how they contributed to the character of 20th and 21st century society.

There are several more industries that characterise the 20th century. The most important among them are the chemical and the pharmaceutical industries. We cannot possibly describe these in any detail without exceeding by far the limitations of this book. All we can do is describe very briefly the rise of the polymer industry, as the so-called plastic materials are so characteristic for the 20th century.

Polymers

Polymers essentially consist of long chains of molecules that form macromolecules. The properties of the polymer depend both on its chemical composition and on the structure of the macromolecules. Many polymers occur in nature, including living organisms. The original macromolecular theory of polymers was propounded in the 1920s and 30s by the German chemist Herman Staudinger, who received the Nobel Prize in Chemistry for this work in 1953. He laid the theoretical foundation for the plastics industry.

Although some polymers were known and in production before World War II, the great expansion in both range and quantity came in the post war period. As early as 1954, the annual tonnage of plastics manufactured became comparable to the tonnage of aluminium and copper.

Among the earliest pioneers of artificial polymers was Christian Frederick Schönbein in Basle, who discovered cellulose nitrate in 1846, produced by a reaction of paper with a mixture of nitric and sulphuric acid. The substance was suitable for the production of various vessels. In 1869 John Wesley Hyatt produced Celluloid that found applications in the production of billiard balls, collars and cuffs, dentures and more besides. Celluloid film enabled the development of cinematography, although it was eventually displaced by the less flammable cellulose triacetate, first made in 1865 by P. Schutzenberger. C. F. Cross and E. J. Bevan patented an improved method of production in 1894, and it came into large-scale production with the introduction of a cheaper solvent. Cellulose acetate was used during World War I for the fabric of aircraft wings. In 1921 it came into use as acetate rayon and this led to a secondary development of dyes made specially for dyeing rayon fabrics.

The Belgian American Leo Hendrik Baekeland held a series of patents, from about 1909, for thermosetting polymers, known (for obvious reasons) as Bakelite. These polymers are made from phenol and formaldehyde and are generically known as phenolic resins. They are used in very large quantities.

One of the earliest and most important industrial polymers is Polyvinyl chloride (PVC), consisting of long chains of the monomer vinyl chloride (CH_2CHCl). Its discovery is variously attributed to the German chemists E. Simon in 1839 or Eugen Baumann in 1872. PVC was originally extremely rigid. It became useful only in 1926, when W. L. Semon of the B. F. Goodrich Company improved its plasticity in a serendipitous discovery by treatment with some solvents. Another process for plasticizing PVC was obtained by the Union Carbide Corporation in 1930, by copolymerization of vinyl chloride with vinyl acetate. Under the trade name Vinylite it became the standard material for the now extant long-playing record. PVC is used extensively in the construction of domestic appliances and for floor tiles, packaging, food containers, toys, thermal insulation and much else.

Elastic polymers, obtained by the German chemical conglomerate I. G. Farben in the 1930s, played a vital role in Germany as synthetic rubber during the Second World War, when imports of natural rubber ceased. The synthetic rubbers, called Buna, were obtained by copolymerization of two monomers in the presence of a catalyst. The name Buna is derived from one of the polymers, butadiene and the catalyst sodium (Na). The second most commonly used polymer to form a copolymer with butadiene is styrene and the resultant synthetic rubber is also known as Styrene-butadiene rubber (SBR). Synthetic rubbers made a vital contribution to the German war effort in World War II, as it was essential for the production of tyres and other vital goods.

Another important class of polymers are the acrylic polymers, such as polymethyl methacrylate produced by ICI under the name Perspex from 1934. It was used extensively for aircraft windows during World War II, and is now used for a variety of purposes. Early work on this class of polymers dates to 1877 and the first commercial product, polymethyl acrylate, was produced by Rohm & Haas in 1927.

Polyethylene and polypropylene date to the mid- to late thirties, with ICI being among the pioneers. These polymers can be produced in various forms and are used mainly for electrical insulation.

In the United States, E. I. Du Pont de Nemours played a pioneering role in the development of industrial polymers. In particular, the class of polymers known as polyamides were largely developed by Du Pont. Neoprene, another rubber-like substance (elastomer), was discovered in 1932 by one of their researchers, W. H. Carothers. Another famous polymer of the polyamide group is Nylon, announced in 1938 as Nylon 66. The development of Nylon took 4 years and employed 230 chemists and engineers. The development cost was $27 million. The first nylon stockings were produced in 1939 and became an instant success as a replacement for silk stockings. By 1962 there were four different types of Nylon on the market, used for different purposes.

As a description of the history of plastics the above brief account is clearly inadequate, but it will serve my purpose of demonstrating how the nature of technological progress changed even between the 19th and 20th centuries, let alone between the 18th and 20th centuries. Whereas in the earlier period the sole inventor, the practical experimenter, the craftsman and the entrepreneur carried innovation on their shoulders, the later period is characterised by technological progress being made only when the necessary scientific foundations had been laid and the technologists and inventors themselves were academically trained engineers or scientists. More often than not inventions and innovations required very large effort in testing and developing, and a lot of expensive scientific equipment to facilitate this work. Obviously, such large financial costs could only be carried by large firms in the hope of reaping large profits. The development of plastics demonstrates these changes particularly clearly. The days of the lone inventor are largely gone, technological innovation is now firmly in the hands of industrial laboratories.

In the 140 years up to 1930, a total of 4239 patents were awarded for inventions relating to plastics. Of these, 43% were awarded to individuals and 57% to firms. In the years 1946 to 1955 a total of 6238 patents were awarded in the field of plastics and of these only 8% went to individuals and 92% to firms. 36% of all these patents went to the eight most important firms in the field. The example of nylon shows the enormous R&D effort required for a major innovation and shows that although leadership is important, it is the research team that achieves innovations and not the individual researcher. If something like 1,000 person-years has to be invested into R&D to achieve a certain innovation, the likelihood of an individual achieving the same result is remote indeed.

R&D has become a highly organised activity demanding a great deal of money. Some of the money comes from state sponsorships provided under miscellaneous headings and a lot of it comes from private firms, mostly large ones and mostly concentrated in a few high-technology industries. The R&D is usually carried out in large industrial research laboratories, but some of it in public R&D facilities. The universities still play a role in technological innovation, mostly through their efforts in pure research, but also in applied research, often carried out in collaboration with industrial firms.

There is no end to the range of products made from plastics, often replacing other materials such as metals, wood, leather, or glass. Virtually all kitchen utensils are now made of plastics and plastics are used in the construction of domestic machinery, in automobiles, in building and in furniture. Plastics reinforced with carbon or glass fibres are now used in the construction of parts that need to be very strong and light, including sections of aircraft. Sports equipment uses similar materials, whether in the construction of skis or of boats and masts. Virtually all weatherproof clothing is made of plastics and plastics play a large role in all other clothing, footwear, household linen and so forth. Were it not the age of information technology, the 20th century might well be called the plastics age.

Epilogue

The 20th century has seen technology move centre stage. This is true in several respects. First, technological innovation has become recognized as the prime factor in economic growth and in the competitive position of firms and countries. Firms have to produce innovations in order to stimulate flagging saturated markets with offers of new products. They have to use improved methods of production in order to compete on costs, but sometimes also on quality and reliability. New production methods are usually designed to save labour, but automated machinery often also works more accurately and with fewer errors than human operators. The result of all this is that industry employs a diminishing proportion of the labour force. A secondary result is that industrial products are now relatively cheap and consequently they get thrown away when they malfunction, because the cost of repairs is relatively high and competent repairers are scarce. From the environmental point of view this is deplorable, as it wastes energy and raw materials, unless the products that are thrown away are easily recycled.

Governments do all they can to stimulate technological innovation. They support much R&D directly, both military and civilian. They also try to introduce all kinds of incentive schemes to promote R&D, whether in terms of tax relief, or in government laboratories, or in attempts to foster R&D cooperation at the national or international level. The European Union is quite active in this field and supports many R&D projects, always run on the basis of cooperation between firms in different countries and often including universities. The proportion of national income spent on R&D, both private and public, is a matter of national pride and governments try to push it up year by year.

Because a high proportion of R&D is always spent on defence projects, governments attempt to get as much civilian benefit out of these projects as possible. Dual use is one of the favourite slogans of the day, meaning technologies that are useful for both military and civilian use.

It has become customary to speak separately of those industries that require high R&D expenditure for survival and call them "High Tech Industries". They include electronics, computers, aerospace, and pharmaceuticals. There is a second tier of industries, including the automobile industry and the chemical industry, that requires substantial R&D effort, though not quite as much as the first group. And then there is the rest of industry, often disparagingly called the old industries, such as textiles, food and drink, bulk chemicals, iron and steel, heavy electrical goods, machine tools, building, and so forth. The division is not very helpful, as the older industries still supply the bulk of our needs, though the so-called sunrise industries supply all the fickle industrial glamour. Industries from high wage countries have transferred many labour-intensive operations to low-wage countries and newly industrialising countries have often concentrated on the older industries because they demand less know-how and are more suitable as measures for import substitution. Textiles and shoes, for example, are now produced largely in cheap labour countries.

The second sense in which technology has moved centre stage is the fact that we are surrounded by it everywhere and all the time. On the street, in the office, in the home, even on holiday we use technology wherever we go and whatever we do. The office is now full of computers, photocopiers, telephones, fax machines (already declining after a very short life), coffee machines, air conditioning, and sophisticated lighting. The street is full (very full) of motorcars, other motor vehicles, traffic lights, mobile phones, and personal tape and CD players. The home is stuffed full of machinery and equipment that did not exist at the beginning of the century; from washing machine to television set and from home freezer to home computer. Domestic machinery has had a big impact on the possibility of freeing the housewife for outside employment, though I do not wish to argue either way whether technology freed the housewife or the free housewife demanded the technology. Perhaps a bit of each.

Medicine has certainly learned to cure many ills, but the technological advances have caused severe financial problems in the provision of medical care for the population at large. People live longer and diagnostic, surgical and therapeutic equipment have become sophisticated and vastly expensive. To make matters worse, technical progress and commercial acumen of the equipment manufacturers are causing rapid obsolescence of medical equipment, so that replacement purchases add to the burden of new purchases. Some argue that the attempts to keep hopelessly ill and suffering patients alive beyond their wishes adds unnecessarily to costs and to the sum total of human suffering. This is undoubtedly true, but the ethical problems that need to be solved to cure this ill are formidable, yet not insoluble. Some tentative steps are being made to take the will of severely sick patients into account when decisions on keeping life-support machinery going or not are being taken.

Advances in travel and in communications have contributed to shrinking the world, for better or for worse. We know more about the world, we see more of the world, but we have to put up with globalization of the economy that is tantamount to our lives being dominated by major global companies. Even in democracies the influence of major industrial players is highly significant.

Military technology has advanced to almost unbelievable levels. Aircraft are incredibly fast and efficient. Modern artillery and its munitions are highly efficient. A whole range of different missiles supplement or supplant artillery. We have surface to air missiles, surface-to-surface missiles, sea to surface missiles and all other combinations of missiles with all ranges and all guidance systems. We have huge aircraft carriers that are virtually floating air bases, escorted by a flotilla of ships with incredible firepower. The modern military engineer has bridges that can be assembled in no time, so that rivers no longer form major natural obstacles. Fortifications and bunkers stand little or no chance against modern bunker-busting bombs. Soldiers in trenches stand no chance against modern bombers. Older tanks stand no chance against their modern counterparts or attack aircraft.

The problems of environmental destruction have changed their nature but have not become less worrying. Whereas at the beginning of the century gross pollution of the rivers by industrial effluent and gross air pollution from burning coal were the dominant problems, we now have made great efforts and more or less cleaned up the rivers, though occasionally chemical spills still kill thousand of fish and insidious pollution persists and causes much harm. We have got our act together and cleared the air from gross pollution, only to replace it by more insidious pollution from car exhausts and other sources that cause the highly worrying greenhouse effect and associated climate change, as well as the depletion of the ozone layer and micro-particles in the air. We still kill our birds by pesticides and fungicides and who knows what else. We are depleting our resources in raw materials and in oil and gas. We are destroying our remaining rain forests, destroying thousands of species of flora and fauna and removing an important part of our source of oxygen. Shall we destroy our habitat completely?

Technology has made us infinitely wealthier. The last hundred years have seen an unprecedented growth of wealth. It has also seen an unprecedented growth in the variety of goods and services available to us. We consume far beyond our needs. Both the supplier and the consumer have become greedy. Yet many people, even in the rich countries, live in relative poverty and not a few in absolute poverty. The poor countries are as poor as ever. Not many people in the advanced countries do physically hard work, but most people have very strenuous jobs and lead fairly stressful lives. What is the balance? Has technology made us happy? If we had a time machine, would we go back a hundred years? Or fifty years? Or not at all?

Technology has become closely associated with science. In fact various branches of physics, chemistry, biology, and mathematics have been integrated into branches of engineering. Applied mathematics, solid state physics, genetics, organic chemistry, to name but a few, operate in a close symbiosis with engineering. It is no exaggeration to say that engineering and science have become a joint activity, with some aspects of each being more practical and applied and some more theoretical and pure. The marriage of science and technology, consummated in the 20th century, appears to be stable and fruitful.

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