The Impact of Motoring

Part 3 - Technological

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http://green.autoblog.com/2013/05/30/biofore-concept-car-is-a-plant-laden-sustainable-ride/

Contents of Part 3

Part 3 - Technological

Over the last 125 years advances in the science of materials and fuels, electronics, communications, computing and software have influenced all aspects of lives, including motoring. Following the “Impact of Motoring” theme, the chapters in this part of the book focus on specific areas of the car, consider the performance and possible effect on our lives of electric cars and conclude with a look at examples of how technology has improved the safety of our motoring lives.

In the early days of motoring, the internal combustion engine was not the only contender for powering cars. Steam and battery power were serious competitors at the start of the 20th century. The fact that internal combustion dominated the century gives a momentum to the development of the internal combustion engine that is not present for other contenders such as re-emerging electric and hybrid electric cars. Hence predicting what the private car will look like in the middle of the 21st century is no easy task. (Assuming that the concept of a *private* car still exists). Clearly many of the world’s major motor manufacturers share this same view as most seek to add at least one electric variant to their model line-up.

In a world of diminishing natural resources and increasing atmospheric (and oceanic) change, influenced by legislation, public opinion and political pressures and aided by ever more sophisticated and affordable electronic hardware, motor manufacturers are producing electric and internal combustion engine cars, that even a decade ago, would have seemed to be unattainable. Some argue that only complete autonomy for the car, namely a car in which all occupants are passengers, will meet the environmental and safety aspirations of legislators.

The Cotswold Motoring Museum exhibition, “A History of Motoring in 10 Objects”, featured the SU carburettor, the Electronic Control Unit, Tyres, the ‘Catseye’ and Seatbelt in the list of significant objects. These appear as chapter headings within this part of the book and remain on display in the museum.

Has the internal combustion engine run its course?

The development of the internal combustion engine from a noisy, inefficient novelty enjoyed by the few to the smooth, powerful all-pervasive component of modern life must rate as one of the most far-reaching and influential developments of the 20th century. This chapter outlines the operation of the internal combustion engine. It looks ahead to alternatives and at further developments that will be necessary for the engine to survive into the mid-21st century: a century in which the ready, affordable availability of fossil fuels that have powered the previous century can no longer be taken for granted.

Introduction

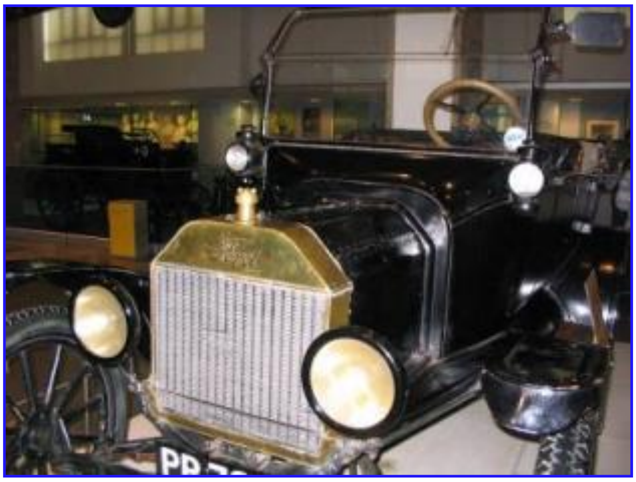
The objective of this chapter is to provide a concise, introductory overview of the history, function and future of the internal combustion (IC) engine. So many high quality articles have been published on this topic, with many of these articles freely available on the internet, that any attempt to better what exists already is going to be a difficult task. Consequently, material has been gathered from various existing sources to meet the objective of the chapter. Hyperlinks or footnotes to original material are provided with the intention of fully acknowledging the original authors. Readers wishing more detail are encouraged to follow these references.

It is easy to think that in the late 19th century and early 20th century, the IC engine was the engine of choice for the newly emerging forms of motorised transport. In fact, this was far from the case; the IC engine faced competition from both steam and electric propulsion. In 1900, a steam-powered car held the land speed record.

The picture above shows a 1900, American, two-cylinder steam powered Mobile on display at the 2010 NEC Classic Car Show in Birmingham. A look at the Steam Car website pages for the 2013 London to Brighton run and the website's photo gallery show just how many steam powered cars remain in private ownership.

The 1903, US built battery-powered Waverley electric car is shown waiting in Hyde Park for the start of the London to Brighton run. In 1900 there were more than 50,000 electric cars in the US.

However, this chapter is about the Internal Combustion engine and it is to that topic that we must return. (Steam cars are, of course, *external* combustion engines; a less familiar term). Cars powered by the internal combustion engine, such as the mass-produced Model T Ford shown here, had an immense influence on the history of the 20th century and, along with other inventions, from the printing press, electric light and textile mills to personal computing and the internet, can be truly described as a 'disruptive technology'.



History of the Internal Combustion (IC) engine

As with the other aspects of the internal combustion (IC) engine, much has been published on the history and major milestones in the development of the IC engine (including the Cotswold Motoring Museum "Motoring Milestones" document). The concise history, from which the following list has been edited, appears on the about.com website

- **1680** - Dutch physicist, Christian Huygens designed an IC engine that was designed to be fuelled with gunpowder.
- **1807** - Francois Isaac de Rivaz of Switzerland invented an IC engine that used a mixture of hydrogen and oxygen for fuel.
- **1824** - English engineer, Samuel Brown adapted an old Newcomen steam engine to burn gas and used this to power a vehicle.
- **1858** - Belgian engineer, Jean Joseph Etienne Lenoir invented and patented (1860) an electric spark-ignition IC engine fuelled by coal gas. In 1863, Lenoir attached an improved engine (using petrol and a primitive carburettor) to a three-wheeled wagon that completed an historic fifty-mile road trip.
- **1862** - Alphonse Beau de Rochas, a French civil engineer, patented but did not build a four-stroke engine (French patent #52,593, January 16, 1862).
- **1864** - Austrian engineer, Siegfried Marcus, built a one-cylinder engine with a crude carburettor and attached his engine to a cart resulting in a drive of 500 feet. Later, Marcus designed a vehicle that ran at 10 mph: considered by some to be the world's first petrol-powered vehicle.
- **1866** - German engineers, Eugen Langen and Nikolaus August Otto improved on Lenoir's and de Rochas' designs and invented a more efficient gas engine.
- **1873** - George Brayton, an American engineer, developed an unsuccessful two-stroke paraffin engine. However, it was considered to be the first safe and practical oil engine.
- **1876** - Nikolaus August Otto invented and later patented a successful four-stroke engine, based on what became known as the "Otto cycle".
- **1876** - The first successful two-stroke engine invented by Sir Dugald Clerk.
- **1883** - French engineer, Edouard Delamare-Debouteville, built an advanced single-cylinder four-stroke engine that ran on petrol.
- **1885** - Gottlieb Daimler invented the prototype of the modern petrol engine - with a vertical cylinder and with petrol injected through a carburettor (patented in 1887). Daimler first built a two-wheeled vehicle the "Reitwagen" (Riding Carriage) with this engine and a year later built the world's first four-wheeled motor vehicle.
- **1886** - On January 29, Karl Benz received the first patent (DRP No. 37435) for a petrol-fuelled car.

- **1889** - Daimler built an improved four-stroke engine with mushroom-shaped valves and two V-slant cylinders.
- **1890** - Wilhelm Maybach built the first four-cylinder, four-stroke engine.

In the last century, the IC engine has continued to develop, both in response to the need for improved performance and, more recently, in response to social concerns over the impact that the IC engine is having on our environment. All vehicles offered for sale in Europe today, have to comply with strict directives on, amongst other things, the noise that they produce, the content of the exhaust gases, their electromagnetic compatibility and their end-of-life disposal. Recognition of finite and increasingly expensive fossil fuels has prompted vehicle manufacturers to invest heavily in developments to improve the efficiency of the IC engine and the development of alternative energy sources.

Common uses of IC engines

The most common use of the IC engine in the transport sector is, of course, to provide the motive force for road vehicles (cars, trucks, motorcycles), although powering boats, aircraft, locomotives and portable machinery are other important categories of use. The fossil fuel powered IC engine has the advantage of a high power-to-weight ratio: a consequence of excellent fuel energy density ie energy produced per unit volume of fuel.

Globally, fossil fuels meet about 82% of the world's total energy needs. Within the European road transport sector, the proportion of energy needs met by fossil fuels currently exceeds this figure. By 2020, sustainable biofuels are likely to comprise only around 8% of the total.

Gas turbines are another form of IC engines – rotary rather than reciprocating – and are used where a very high power is required, such as in jet aircraft, helicopters, tanks and large ships. They are also frequently used for electric generators and by industry. Mainly because of high cost and high fuel consumption, they have not been used in production cars. The first jet-powered prototype Rover resides in the London Science Museum and, in the early 1960s, a number of gas turbine powered Rovers competed successfully at Le Mans.

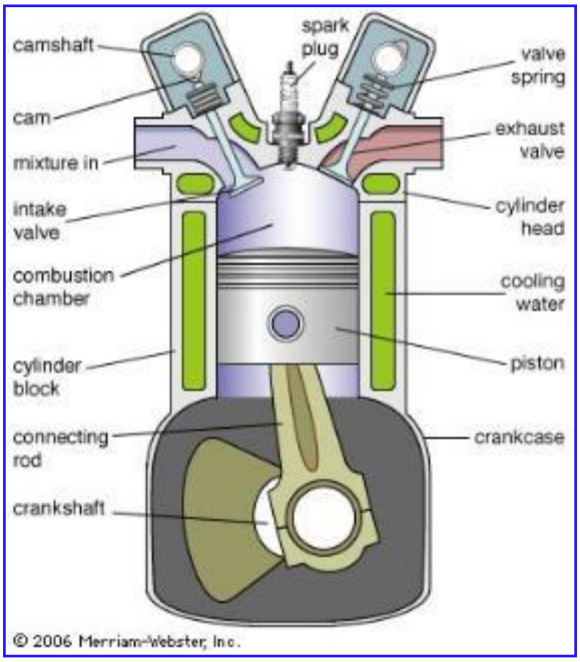
How does the IC engine work?

An internal combustion (IC) engine is any engine that uses the explosive combustion of fuel to push a piston within a cylinder. The most commonly used fuels for car IC engines are petrol and diesel: both of which are fossil fuels. In summary, they convert chemical energy to mechanical energy with heat as a significant by-product. The piston's linear movement turns a crankshaft – converting linear motion to rotational motion - that then turns the car wheels via a clutch, gearbox and final drive assembly.

The following sections provide a brief overview of the operation of the four-stroke petrol and diesel engine, the two-stroke engine and the rotary Wankel engine. The following short chapter outlines the principle behind the operation of a carburettor; a key component in 20th century motoring.

How a four-stroke engine works

The diagram to the right shows a cross-section of a single cylinder of a twin-camshaft IC petrol engine.



The intake valve allows the combustible mixture of fuel and air into the cylinder. As the inlet valve shuts, the rising piston compresses the mixture. When the piston is near the top of its stroke (typically a few degrees before 'top dead centre') a high voltage electrical discharge across the gap in the spark plug ignites the mixture forcing the piston down. On the next rising stroke of the piston, the exhaust valve opens and the waste gases from the combustion are expelled past the exhaust valve.

So, in summary the four strokes of this engine are:

• Intake or Induction		Suck
• Compression	*sometimes referred to*	Squeeze
• Power	*as a memory aid as*	Bang
• Exhaust		Blow

Most vehicle engines today are four stroke engines with the four strokes (intake, compression, power and exhaust) occurring during two crankshaft rotations per four stroke cycle.

For further information and an animation of the 4-stroke engine, follow the Wikipedia link.

How a diesel engine works

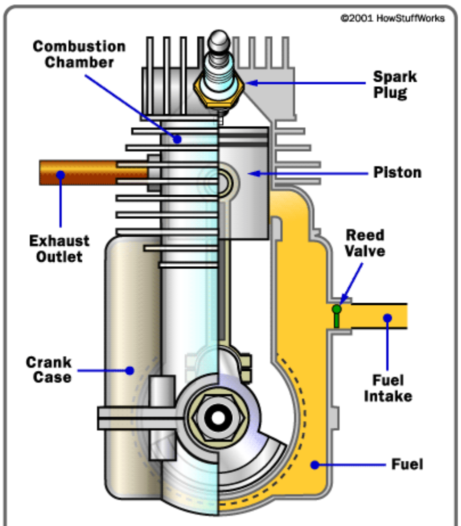
A diesel engine is an internal combustion engine that uses the heat generated by the compression of air in the cylinder to initiate ignition of fuel, which is injected into the combustion chamber during the final stage of compression. A cross-section view of a four-stroke diesel engine would look very much like the earlier picture of the petrol engine but with the spark plug replaced by a fuel injector. To aid cold starting a glow plug – basically a small electrical heater - in each combustion chamber provides a few seconds of pre-heating. The duration of the glow plug operation is indicated to the driver by an illuminated, coil-shaped warning lamp on the instrument cluster.

The engine operates using the diesel cycle (named after Rudolf Diesel). For a given engine capacity, a turbocharged diesel engine will provide better efficiency than the corresponding petrol engine. In part, this is due to the higher density of the diesel fuel which contains, for a given volume, around 15% more energy than petrol and the higher compression ratio of the diesel engine.

For further information, follow this link and for an animation of a diesel engine cycle see the following link.

How a two-stroke engine works

A two-stroke engine is an IC engine that completes the cycle of intake, compression, combustion and exhaust in two sweeps of the piston compared with four for a four-stroke engine. This increased efficiency is accomplished by using the beginning of the compression stroke and the end of the combustion stroke to perform simultaneously the intake and exhaust functions. Two-stroke engines can often provide a high power to weight ratio in comparison with a four-stroke engine. Petrol versions are widely used in lightweight, portable machinery such as chainsaws, generators and gardening and building equipment. Typically, such two-stroke engines are air-cooled and the lubricant is mixed with the fuel in a ratio of one part lubricant to 50 parts fuel. The role of the valves in the four-stroke engine is replaced by ports that are exposed or covered by the piston as it moves through the cylinder. Consequently, the two-stroke engine is a much simpler device than the four-stroke, with fewer moving parts and no coolant or lubrication passages.



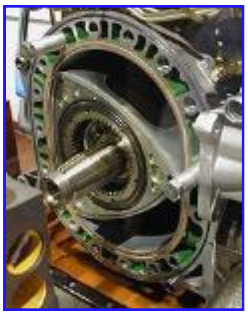
The basic components of a two-stroke engine

The concept is also used in diesel compression ignition engines in large and non-weight sensitive applications such as ships and locomotives. The disadvantages of two-stroke engines have been associated with the burning of lubrication oil and expulsion of unburnt fuel from the exhaust system resulting in the, now unacceptable, blue smoke typified by the East German Trabant in the 60s, 70s and 80s. Developments in two-stroke design however have gone some way to reducing these drawbacks.

For further information, follow the Wikipedia link.

How a Wankel rotary engine works

Rather than use the pressure generated by fuel combustion to produce a linear motion, which in a reciprocating engine is then converted into a rotational motion, the Wankel engine uses a rotary design to convert a pressure differential directly into a rotating motion. Its four-stroke cycle takes place in a space between the inside of an oval shaped combustion chamber and a rotor that is similar in shape to a Reuleaux triangle. The image shown is reproduced from the prelovac.com website.



This design delivers smooth power at high revs, from a compact size. There are fewer moving parts than in a corresponding piston engine and catastrophic failure (eg as a result of over heating) is uncommon. On the down side, the Wankel engine tends to be less fuel efficient than the piston engine and successful sealing between the rotor and combustion chamber has, historically, been a design challenge. The most extensive automotive use of the Wankel engine has been by the Japanese company Mazda.

Improving the efficiency of the IC engine

Developments of the IC engine to improve performance, economy and environmental impact are moving rapidly and have a momentum that many of the alternative power sources do not possess. Some pundits predict that by 2050, "most energy will still be derived from fossil fuels …. nuclear power will account for an increasing share of global electricity production, while wind and solar power will still be negligible"[1]. In the automotive sector, Uwe Kracht of Mazda Europe is convinced that "in 2020 more than 80% of cars will still use combustion engines"[2]

So with that in mind what can be done? The government's climate change watchdog recently warned that Britain should not rely on fossil fuels to produce power in 20 years' time. There are four key issues about conventional oil that have been apparent for at least a decade – declining output, declining and less accessible discoveries (eg beneath the ocean floor and beneath arctic ice), increasing demand and insufficient alternative energy projects in the pipeline. Automotive manufacturers and their suppliers are continuously improving the efficiency of the IC engine; helping to conserve remaining conventional fossil fuel supplies.

The efficiency of the automotive IC engine has improved from around 5% in 1900 to around 40% during the century that the IC engine has been in popular use. If the energy losses in the vehicle drive train, accessories, rolling resistance and aerodynamic drag are taken into account then typically less than 15% of the power produced by the burning fuel appears at the wheels of the car. Some measures to improve the IC engine efficiency are outlined below.

- One significant step in the continuing increase in efficiency of the IC engine has been the advent of variable valve timing. In the earlier diagram of the IC engine, it is clear that the twin camshafts are the means by which the opening and closing of the inlet and exhaust valves are controlled. With no means of adjusting the valve timing as the engine speed changes, the cam profile (for single or twin cam) is optimised to provide a compromise between good high speed performance and smooth running at tick-over. It will yield best engine efficiency at one specific engine speed. The advent of electronic engine control has enabled various designs of variable valve timing to be implemented. Techniques include enabling an alternative cam profile to switch in at high engine revs, variation of the timing of the existing camshaft(s) or providing continuously variable timing with engine speed: for example, by using solenoids to control valve operation.

- Cylinder deactivation, or variable displacement, saves fuel by deactivating cylinders when they are not needed. This is achieved by keeping the intake and exhaust valves closed for a particular cylinder while also cutting the cylinder's fuel supply. The result is improved fuel economy and reduced emissions. The technology has been around since the early days of internal combustion engine, but it is only recently, with the use of sophisticated engine management systems, that it has demonstrated its full potential. Powerful and fast on-board computers mean that deactivation and reactivation occurs almost instantly and there is little sacrifice of power.

[1] Michael Lind, TIME Magazine, 22 March 2010
[2] Autocar, 29 February 2012.

- Stop/start technology: sometimes known as mild hybrid technology, it automatically turns the engine off when the vehicle is stopped to reduce fuel consumed during idling. This feature is particularly advantageous for city vehicles. In order not to lose all functions when the engine stops, regenerative braking is used to convert mechanical energy lost in braking into electricity, which is stored in a battery or capacitor and used to power accessories, like air conditioning and the automatic starter. A Kinetic Energy Recovery System (KERS) was a feature of Formula One racing for a few seasons until, in 2014, it was replaced by a much more significant Energy Recovery System (ERS) using both kinetic and heat energy to supplement the power from the internal combustion engine.

- Turbochargers increase engine power, with lower fuel consumption, allowing manufacturers to downsize engines without sacrificing performance or to increase performance without lowering fuel economy. Turbochargers, powered by exhaust gases from the engine, force compressed air into the cylinder generating extra power from each ignition. The engine specification for the 2014 Formula One season has replaced the 2.4 litre V8 with a 1.6 litre V6 engine. To help maintain the power output of these new, hybrid power units, the turbochargers spin at up to 100,000 rpm[3]. In the aftermarket, electric superchargers are available, sometimes used in conjunction with a conventional turbo. They spin up faster than a conventional turbocharger and eliminate turbo lag. They are now also being adopted by OEMs[4].

- All but one of the cars on permanent display in the Cotswold Motoring Museum use carburettors to provide the engine with the correct fuel/air mixture. Modern vehicles rely on the more efficient fuel injector for this task. In these multi-port fuel injection systems, fuel is injected into the port and mixed with air before the air-fuel mixture is pumped into the cylinder. In direct injection systems, fuel is injected directly into the cylinder so that the timing and shape of the fuel mist can be precisely controlled. This allows higher compression ratios and more efficient fuel intake, which deliver higher performance with lower fuel consumption.

- Exhaust heat recovery. Much of the energy released by burning fuel in the IC engine is lost as heat via the exhaust. Automotive designers are working on methods to harness this heat to produce more power for the engine. Exhaust gas recirculation is already a common technique used to pre-warm the fuel air mixture. Potentially, this heat can also be used to create steam to drive the engine or used to generate electrical power via thermoelectric devices.

- Split-cycle engine technology has been developed by Scuderi Engine in the USA. They implement the four-stroke IC engine and conventional combustion cycle over two paired cylinders: one intake/compression cylinder (with no spark ignition) and one power/exhaust cylinder. The compressed air in the intake/compression cylinder is fed, at around 50 bar (~725 psi), into the power/exhaust cylinder and ignition takes place (unconventionally) after top-dead-centre. This engine requires just one crankshaft revolution to complete a combustion cycle whereas the conventional engine requires

[3] New Scientist 15 March 2014
[4] Original Equipment Manufacturers

two. Improvements are claimed in efficiency, emissions and torque over conventional petrol or diesel engines. The reference link contains a good animation of the cycle.

- Two and four-stroke engines have been described above but what about five and six stroke engines? Ilmor Engineering from Northamptonshire has been working on a five-stroke engine which delivers high power output with low fuel consumption. In the USA Bruce Crower has been working on a six-stroke engine. Following the exhaust stroke, water is injected into the engine and ‘waste’ heat generated by burning fuel in the engine is used to produce an additional power stroke delivered by steam. A final exhaust stroke completes the cycle. This means that instead on one power stroke in four, the engine has two power strokes in six and less heat is wasted.

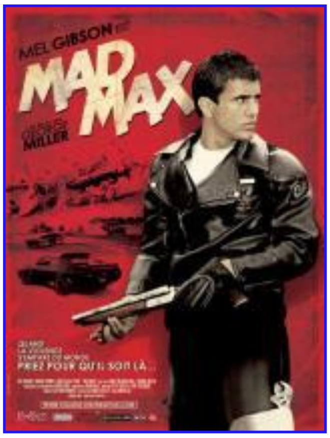
- Finally, a natural gas (90%) / diesel (10%) hybrid has been demonstrated by ETH in Zurich that produces half of the CO_2 of the corresponding diesel engine. Given the ascendancy of natural gas production in the US market, this may prove to be highly relevant.

Conclusion

Many of us, of a certain age, remember the Mad Max film that launched the career of Mel Gibson. It is sobering to recall that this was over 30 years ago! The film depicted a terrifying view of a world without oil, where gangs of grisly looking people roamed deserts in a post-apocalyptic world, killing each other to get their hands on the few drops of petrol that some had managed to produce in makeshift refineries. Social order had completely broken down.

This may all sound a bit far-fetched but just think back to summer 2008 when oil prices spiked to $147 a barrel – 10 times the level of a decade earlier. In petrol stations in some European countries, people started to drive off without paying and drivers had to be banned from filling their cars before they had paid. In Britain, people stole heating oil out of the tanks that sit outside many houses in the country. The future of the IC engine must have seemed pretty bleak at that point.

Although alternative forms of energy are currently under development most of them are still a long way from market-ready. One could argue that with the abundance of fossil fuel and its suitability for so many uses there has been a reluctance to invest in costly R&D projects to find alternative fuel types. With increased public and private sector support, it may be possible to speed up the development of these technologies and help free ourselves from such a heavy reliance on fossil fuels. Surely, it is better to save these increasingly scarce resources for pharmaceutical and industrial use than to simply burn them?



Oil companies will have to play their part since, with the finite life of fossil fuels, they would stand to reap enormous short to medium-term profits but, in the long term, their business would ultimately disappear. Driven by ever tightening vehicle emissions legislation, oil and other energy companies are working with automotive companies to develop technologies to both extend the life of and ultimately perhaps to replace the IC engine. Their own commercial survival, once all fossil fuel resources are exhausted, or no longer commercially viable, will be dependent on the outcome. The worrying thing is if we do not give sufficient priority to this task, it may be too late and we may have to face a Mad Max scenario.

A less melodramatic scenario is one of continuing incremental improvements in the efficiency of the IC engine over the first few decades of the 21st century, driven by legislation and cost, up to the point where the ability to produce hydrogen for our fuel cell-powered transport becomes affordable and carbon-free.

Hopefully the IC engine will pass gracefully into history, maybe around the middle of the century, to be replaced with another 'disruptive technology': this one based on hydrogen.

Picture Captions and Credits

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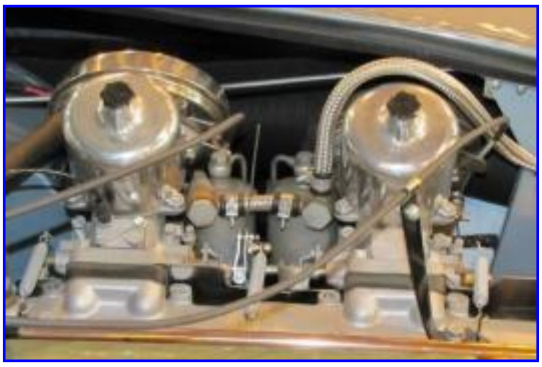
Lilley and Skinner for shoes or a handbag maybe but a carburettor?

For an internal combustion engine to work efficiently, the correct mixture of atomised fuel and air has to be delivered to the cylinders under all conditions of temperature, engine load and throttle opening. Until relatively recently this was achieved by way of a carburettor. And Lilley & Skinner …… ? Read on!

What is a carburettor?

A quick answer is that it is a component, which until recent years, was used with all petrol-engine cars. It produces the optimum mix of atomised fuel and air over the range of engine operating speed, load and temperature. This chapter goes on to explain why that is important, how it is achieved and to outline the development of one of the major designs of carburettor.

Ever since the invention of the internal combustion engine, devices for delivering a volatile mixture of fuel and air to the engine have evolved. One such iconic design is the SU carburettor: one in which both the air and fuel passages vary in accordance with the requirements of the engine. It was first designed and patented in 1905 by George Herbert Skinner and named SU after 'Skinner Union'. The family business was the manufacture of shoes, specifically the company of Lilley and Skinner: once a household name with a presence on most High Streets. In August 1910 Herbert, as he was known, along with his two brothers, registered the SU Carburettor Company Limited, in London. The company steadily grew, and by 1912 the factory was producing carburettors in large numbers. During World War I the company, like many others, was involved in munitions production, together with production of carburettors for aero engines.



After financial difficulties, ownership of the company changed to Morris Motors in 1926. Sound financial backing resulted in new models in 1929, and further aero engine types in 1932: one was used with the Rolls-Royce Merlin engine in the Spitfire, Hurricane and Lancaster aircraft. Another was used on the Napier engine, which powered the Tempest and Typhoon. During

WWII it was vital that production was secured, so 'shadow' factories were built in Birmingham. The company also developed a fuel injection pump for the Merlin engine.

After the war, production of carburettors and fuel pumps resumed, the company moving to a new site, and by 1947 production was approaching 223,000 units per year. Mr C T Skinner sold the fuel injection manufacturing business to the American company Stirling, and although not pertinent to the mass-produced car at the time, development in the 1980's meant it would become so.

The SU Company became one of the major fuel system suppliers in Europe, with its designs used in many motor vehicle engines. Wikipedia lists these manufacturers: including Austin, Morris, Triumph, MG, Hillman, Rolls-Royce, Daimler, Morgan, Riley, Jaguar, Wolseley, Saab and Volvo. The Hitachi Company in Japan manufactured derivatives for the Datsun 240Z and 260Z and other Datsun models. Until 1995, the Rover Group used variants in production cars: the Mini, Metro and Maestro.

The company subsequently changed hands several times. SU carburettors and fuel pumps are now manufactured, together with spares and reconditioning kits, mainly for the classic car market, by Burlen Fuel Systems Ltd. Documents on the Burlen Fuel Systems website, dating from 1974 and 1963, cover in detail the following brief outline description of operation.

How does it work?

Early SU carburettor models included a fine high quality hand stitched leather bellows [5] (a link to the shoe making business?), which held a tapered needle, inside an orifice or 'jet'. When the throttle opened the airflow through the carburettor increased, the bellows would rise taking the needle out of the stream of air, delivering a greater amount of fuel into the engine. This basic operating principle, once production challenges were overcome, became a feature of all further models the company would design and manufacture.

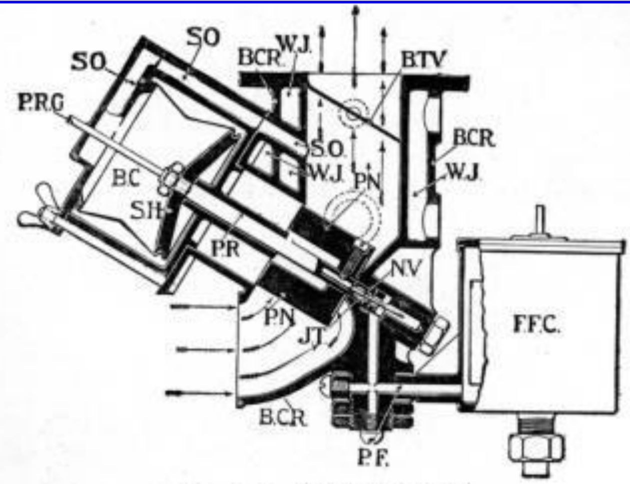


Fig. 157.—S.U. Carburettor.

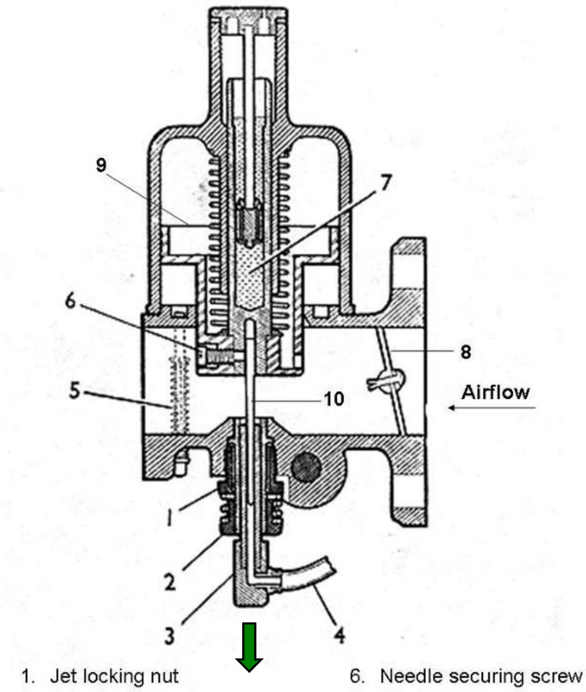
This piston is capable of sliding up and down in its cylinder, guided by the piston rod PR, which carries at its upper end a mushroom suction disc forming the bottom of a bellows suction chamber BC.

The carburettor works on Bernoulli's principle. This states that:

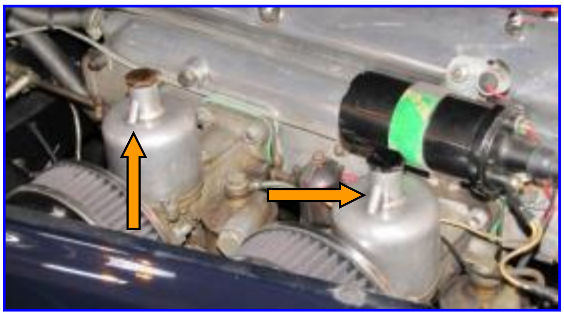
[5] "The Book of The Motor Car Volume 1" by Rankin Kennedy, published by Caxton, London in 1913 (and still available on EBay) shows cross-sections of early SU carburettors in which the bellows can be clearly seen. The two images above are reproduced from this book.

"*The pressure in a fluid* [in this case the air] *decreases as the speed of the fluid increases".*

Relating this principle to the SU carburettor, the accelerator pedal linkage controls the flow of air drawn into the engine: in the case of the cross-section diagram of the SU carburettor on the right, this control is via a throttle plate or butterfly valve (8). The air drawn into the engine speeds up as it passes through the restricted carburettor body (which acts as a venturi) and produces a reduction in pressure above the piston (9) causing it to rise. A tapered needle (10) attached to the piston is withdrawn from a fuel jet, allowing more fuel to mix with the air. (Not visible in the cross-section diagram but indicated by the orange arrows in the picture below, is a passage in the carburettor casting that equalises the reduced pressure in the venturi with that on the upper side of the piston). With the lower side of the piston at atmospheric pressure, the piston rises against its own weight, resistance from a spring and oil-filled damper (7), thus enriching the fuel mixture. The profile of the needle and the strength of the spring are designed for optimum fuel-air mixture over the range of engine operation.



1. Jet locking nut
2. Jet adjusting nut
3. Jet head
4. Fuel pipe from float chamber
5. Piston lifting pin
6. Needle securing screw
7. Oil damper reservoir
8. Butterfly valve
9. Piston
10. Needle



The original SU design did not incorporate a device for cold starting; this requires a temporarily rich fuel mixture. Wolseley Motors Ltd included the addition of a second jet, operated by the driver when cold starting was required, to overcome this deficiency in design.

The cold-starting control on later SU models acts on the jet assembly, drawing it downwards in the direction of the green arrow in the cross-section view above. Lowering the jet increases the area between the jet and the tapered needle allowing an increase in fuel flow until the engine approaches working temperature. The driver action of pushing the choke control knob fully in raises the jet assembly and the fuel enrichment ceases.

Since petrol is pumped, either mechanically or electrically, from the fuel tank to the carburettor(s) – very rarely it is gravity fed - it is necessary to control the supply of petrol to the jet(s). This is achieved by a float chamber (effectively a small reservoir) linked to, or integral with, each carburettor body. The flow is regulated by a float and needle valve in the chamber(s). As the float rises, so the needle valve closes, reducing the flow of petrol from the pump. As fuel is drawn into the engine via the jet, the float will drop sufficiently for the chamber to remain full.

This design of carburettor, one in which both air and fuel passages can be varied, as the engine requirements change from idle to full power, is a simple design, and provides good flexibility and economy of manufacture, and a good atomisation of fuel under all operating conditions.

What is the future of the carburettor?

In the last few decades, atmospherically aspirated carburetion has been replaced by fuel injection by virtually all modern car manufacturers. Fuel injection was once considered the rich man’s way of using petrol, and with poor economy and only modest increases in engine performance, it only found its way into expensive and high performance cars with many cylinders. With the massive leap forward in electronics, computer technology and hence electronic engine management, the direct injection of accurately measured amounts of fuel has become not only possible, but now common place in almost all car engines. It is the only way manufacturers can reduce vehicle emissions to meet environmental legislation. Even the last of the Rover cars produced, which had relied extensively on the SU Carburettor, for example the Rover 1.1 (Metro), had fuel injection.

In the more recent past, the enhancement of air induction into fuel injected car engines has become more common due to developments in turbocharger technology. For many years this technique, which uses the power of the exhaust gases leaving the engine to rotate a turbine, connected to an impeller that sucks cool air into the engine, was only found in diesel and high performance petrol engines. It is now common to find a small turbocharger in petrol engines of small hatchback and family cars, to enhance performance and fuel economy.

The place of the SU carburettor, having played such an important role in the motor industry for over 80 years, is now confined to the more limited but never ending classic car markets and historic racing, where it should live on forever. Many classic vehicle websites and manuals cover the reassembly and setting up of the carburettor(s), so continuing to extract optimum performance from SUs is not difficult.

Finally, the twin SU carburettors on the nearside of this 4½ litre, supercharged ‘Blower’ Bentley are clearly visible for all to see.

Picture Captions and Credits

Page 15: Images of single, twin & triple carburettors taken at the Classic Motorshow, NEC, Birmingham, in November 2011.
Page 15: Twin SUs in a 3 litre Austin Healy. NEC Birmingham, November 2011
Page 16: Images of early SU carburettor taken from "The Book of the Motor Car, Volume 1" published by Caxton, London in 1913
Page 16: SU Carburettor: http://www.mgexperience.net/article/images/su-hs4-section.gif
Page 17: Twin SUs showing exterior of the channel used to create a pressure drop above the piston
Page 17: Carburettor body and float chamber on display at the Cotswold Motoring Museum and Toy Collection, Bourton on the Water
Page 18: A pair of SUs on a 4½ litre 'Blower' Bentley

Have electronics made the car too complicated?

This chapter on The Electronic Control Unit (ECU) attempts to describe some of the benefits of electronics and software to the car as well as considering the effects of increasing complexity, the implications for non-franchised motor dealers and the slow demise of motoring DIY.

Introduction

Modern cars are full of electronics, making them complex, difficult and expensive to service without specialist equipment and generally beyond the DIY skills of the vast majority of owners. There is a school of thought that says: surely, this is not the route to a sustainable, environmentally friendly future?

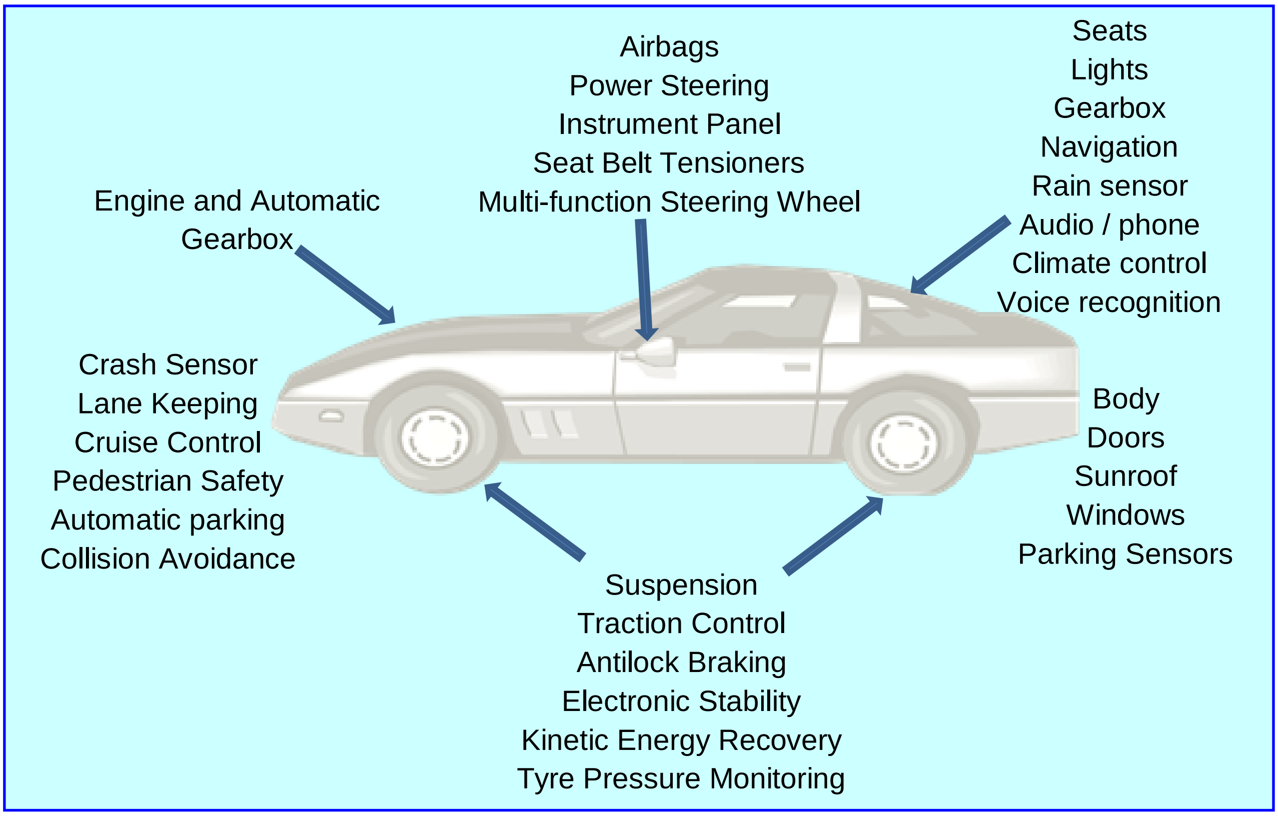
By value, electronics and software represent 35% to 40% of the cost of building a luxury car and one estimate suggests this could rise to 50% within a decade. Even a medium sized family saloon may have several tens of ECUs, each with its associated multiple electronic sensors and actuators, embedded in the body, doors, dash, seats or roof lining. Cars are complex and becoming increasingly so. One estimate is that 50% of ECUs exchanged by a garage technician exhibit neither software nor hardware faults: following diagnostics, replacement is the only option open to the technician. So, maybe there is merit in the earlier assertion?

The Cotswold Motoring Museum selected the ECU as one of the 10 most influential objects in the history of motoring. This selection is certainly not based on any aesthetic quality!

Siemens engine management ECU

Typically, an engine management ECU appears as a metal or metal-lined plastic box with one or two multi-pin connectors along the box edges. The Siemens unit to the right measures around 160x140x30mm.

Reasons for the ECU being in the top 10 include the environmental benefits such as cleaner exhaust gases, the social benefits such as the widening demographic spread of car owners and drivers, as well as performance and safety enhancements only achievable through the use of electronics and software. Virtually every function of the car is now influenced or directly controlled by an electronic ‘black box’. Just how widespread are the functions that depend upon the presence of an ECU and its embedded software is shown in the illustration below. For a hybrid vehicle, the list would be longer!



Typical functions of the Electronic Control Units (ECU) around a modern car

Throughout the 20th century, as cars became 'easier' to own and drive, so the number on the roads of developed countries soared. As examples of why cars became 'easier' to own and drive, consider: the advent of the electric starter motor, avoiding the need for hand cranking an engine, pneumatic tyres, improving ride comfort, power assistance for steering and brakes, and the automation of choke control and ignition timing - mentioned in the Prior Art panel below. Couple this with the real terms decreasing cost of purchasing a car[6], and it is easy to see why the number of cars on UK roads has grown from 14 or 15 in 1895 to 9.97 million in 1970 to 29.2 million today. Just as electronics has transformed the way we communicate with each other, the way commerce functions and the way we spend our leisure time, so electronics in the car has played a major role in the convenience, performance, environmental emissions, safety and affordability of cars over the last 40 years.

Performance, reliability, economy and emissions

In terms of the car's performance, reliability, economy and emissions, electronic control of the engine has had a profound influence. The engine ECU ensures optimum fuel combustion within the cylinders.

[6] See the chapter on "Responsibility of Ownership"

The Prior Art. Whilst today, electronics and software provide solutions to problems that the motorist of 50 years ago may not even have realised he faced (and it generally was a ‘he’), how did the very early motor manufacturers provide solutions for the most fundamental functions performed today by electronics and software?

1911 Alldays & Onions

Take the basic function of producing a spark in each cylinder, at the appropriate time, to ignite the fuel / air mixture. The earliest car in the Cotswold Motor Museum is the Alldays and Onions 1911 Victoria. It has no battery, an air horn and acetylene and oil lighting. The only hint of anything electrical is the magneto, used to generate the high voltage applied in sequence to each sparking plug to burn the fuel. Levers in the centre of the steering wheel adjust the timing of the spark, along with control of the throttle opening. Advancing or retarding the timing of the ignition to achieve optimum starting and running was, in 1911, a purely manual task.

Advance / Retard lever

As vehicle design progressed, so the manual adjustment of the ignition timing became automated. Mechanical, centrifugal advance, which varied the timing depending upon the engine speed, and vacuum advance, which used the pressure in the inlet manifold to vary the timing, were introduced. In the late 1960s and 1970s, the (by now) conventional distributor components of contact breaker points and a condenser (capacitor) were starting to be replaced by electronic ignition; often as an after-market exchange, to improve reliability and performance.

Also in the 60s and 70s, electronic DIY kits existed to provide intermittent wiper actions, rev counters were becoming electronic, a few basic trip computers appeared in the US market and valve radios were being replaced with solid-state units.

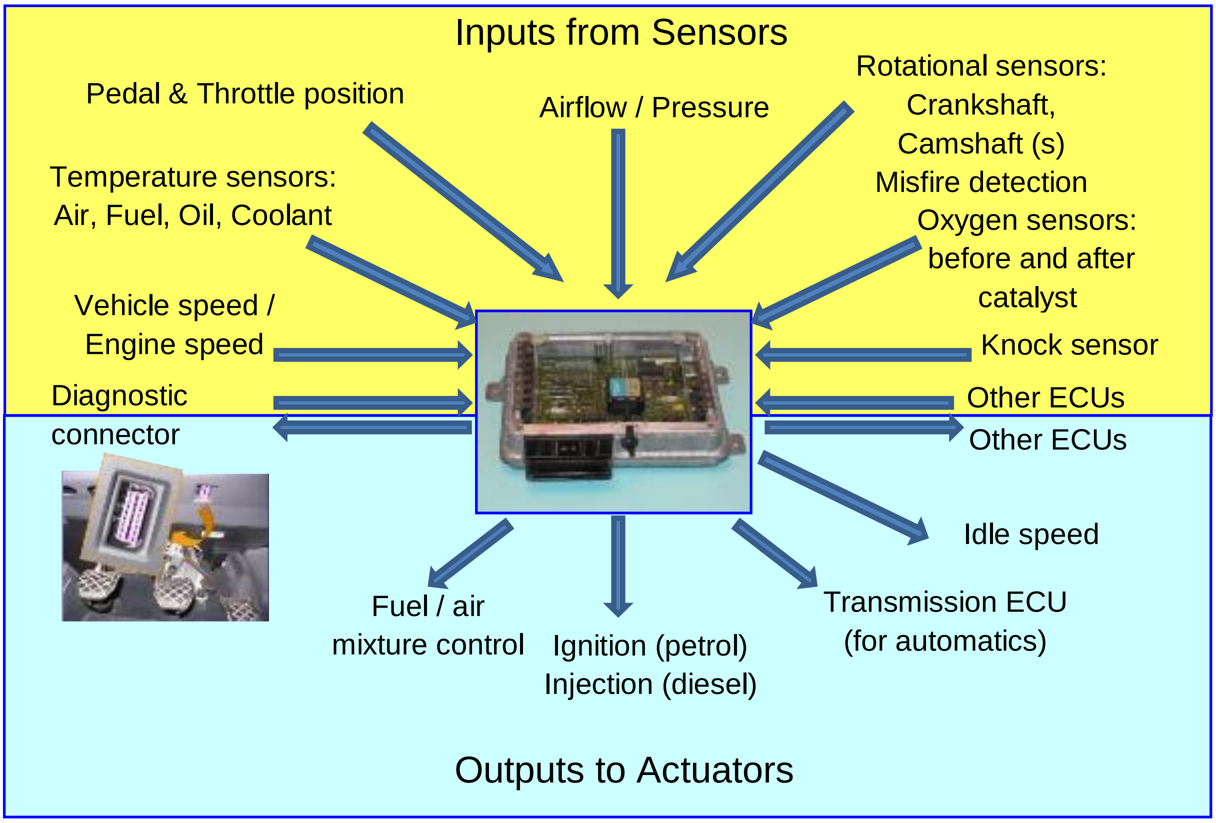
Garage diagnostics were performed using the type of diagnostic equipment produced by companies like Crypton or Sun; both of which feature in the Cotswold Motoring Museum display.

Electronic control of the drive train ensures optimum engine revs for a given gear ratio and improves the fuel efficiency of even small cars with an automatic gearbox. Such control, only possible through the use of electronics and embedded software, minimises particulate and gaseous exhaust emissions that are harmful to our health and our environment and has enabled vehicle manufacturers to keep pace with increasingly stringent US and European legislation on emissions.

Of all the areas of the motor car where electronics has been influential, management of engine functions has been the most far reaching.

Fuel economy and exhaust gas cleanliness have seen major improvements from the adoption of electronics and software in the car.

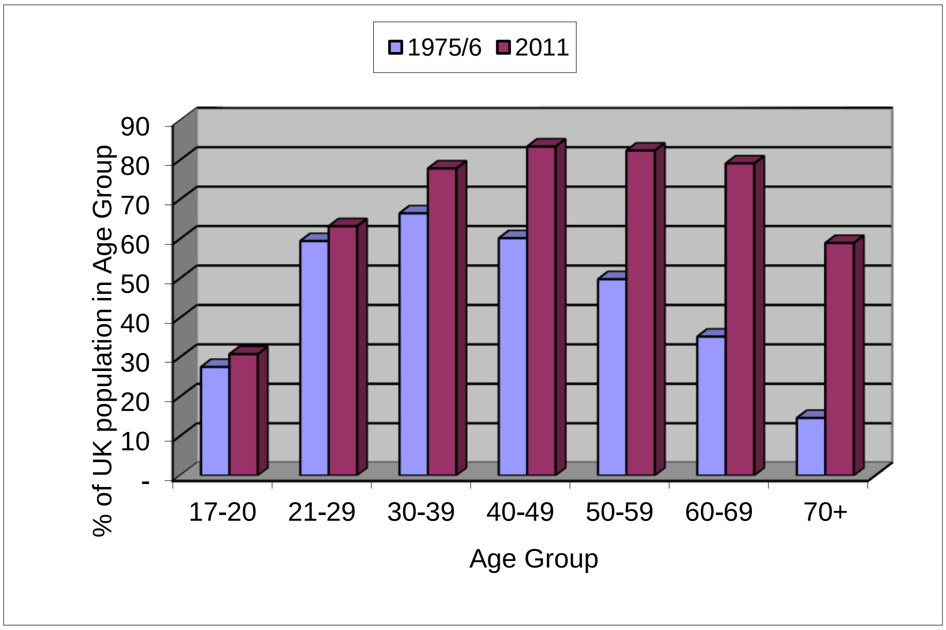
The Engine Management ECU



The Engine Management ECU—inputs and outputs

Driveability, comfort and convenience

Year-on-year, the average age of the population of the US, Japan and Europe is increasing. As the chart on the next page illustrates, the proportion of the UK adult population holding a full driving licence has increased in all age groups since the 1970s. However, the largest percentage increase has been in the 70-plus age group. To these drivers, whose representation is set to increase up to 2035, driveability, comfort and convenience are key considerations when buying a car. Reversing and parking aids, seat position memory, suspension settings, automatic light and wiper operation and interior climate control are all likely to be on the list of selected options.

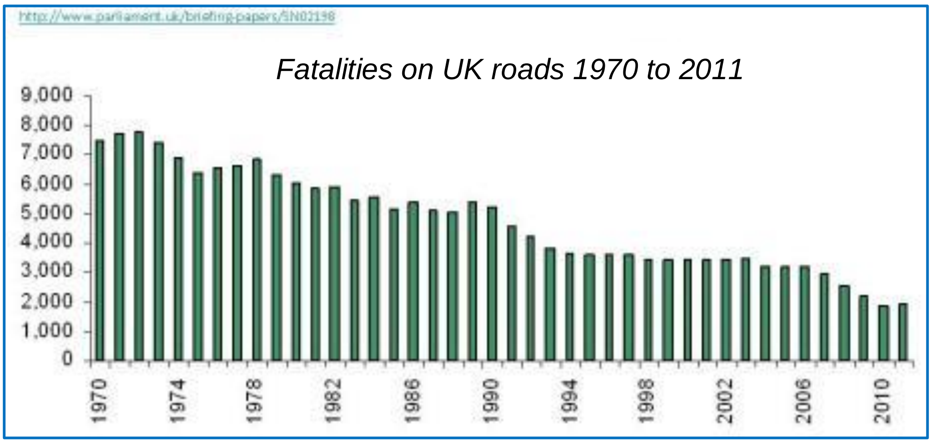


These features plus audio (digital audio broadcast or internet radio), in-car traffic information and navigation are features that are only possible through use of electronic memory and processing. Looking to the future, the increasing use of data buses around the vehicle and the electrical control of steering, throttle and brakes (the drive-by-wire concept) are helping to reduce vehicle weight and hence improve economy and drivability. Virtually autonomous vehicle control in the event of an emergency, along with an automated 'E-call' to the emergency services, is already well established in the development programmes of manufacturers such as BMW and Mercedes and is encouraged by European Union initiatives aimed at reducing injuries on the road.

Passive and active safety

In 1970, there were 7,499 fatal accidents on UK roads. In 2011, there were 1,901 fatalities with 833 being car occupants. Over this 41-year period, the number of vehicle miles (ie the number of vehicles on the road multiplied by the average annual mileage) has increased by 144%.

The contribution of electronics in cars to both passive and active safety has undoubtedly made a major contribution to that decrease. Seat belt pre-tensioners, airbag deployment, anti-lock brakes, electronic stability control and increasingly, emergency braking, lane keeping, collision avoidance and pedestrian safety, all owe their existence to the introduction of electronics to the car.



The future

Returning to that 50% statistic quoted at the beginning of this chapter (ie 50% of ECUs exchanged by a garage technician exhibit neither software nor hardware faults); how is this wastage to be reduced? A trend, particularly in the franchised dealer network, is to change the role of the workshop technician in the diagnostics process. With a secure data connection made between the diagnostic port of the car and the manufacturer's remote diagnostic system, the technician's role then becomes one of providing input to the computer-led diagnostic process and of taking the recommended actions, such as cleaning connectors, changing a sensor, authenticating software updates etc.

So, is there no downside to this takeover of vehicle functions by the all-pervasive ECU? Clearly, there are some and they tend to be those that affect both the vehicle repair market and the vehicle itself. As outlined in the previous paragraph, manufacturers would like to keep the end user of the vehicle heavily dependent on their network of franchised dealers. Whilst there are sound technical and quality control reasons for this, one obvious impact is that the non-franchised repairer, the roadside repair organisations and the DIY repairer will quickly be squeezed out of the picture when dealing with ECU-related faults. Such an outcome has long been viewed by the European Commission as anti-competitive and current legislation, primarily focused on cleaner vehicle emissions (Euro 5/6), includes requirements for the vehicle manufacturers to make repair information and diagnostic data available outside of the franchised dealer networks at "reasonable and proportionate" cost.

In spite of EU legislation and pressure from the independent sector requiring access to motor manufacturer's repair information, the manufacturers are reluctant to make software, such as updates and security software, available to repair organisations outside of their direct control: their argument being that these are not required for maintenance and repair. This clearly limits the range of tasks that can be undertaken by the independent and DIY repairer.

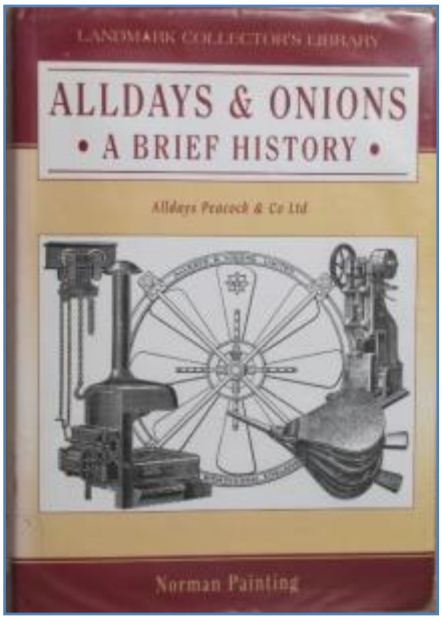
What is the future of electronics and software in the car? There seems little doubt that as it becomes ever more imperative to maximise remaining reserves of affordable oil, the development of new cars will be driven by maximising fuel efficiency and minimising CO_2 emissions over the life of the car. These objectives will only be met by ever more complex vehicle and engine management systems. One estimate is that 50% of the value of a non-hybrid car and 80% of the value of a hybrid will be down to electronics and software costs.

Tighter integration of an increasing range of vehicle components with the vehicle data bus is another feature of modern vehicles. Manufacturers claim that programming the code of replacement components, such as the battery, brake pads, switches and even light bulbs into the relevant ECU is the way to maximise fuel economy. Similarly, cancelling warning lights – such as a service indicator or a brake pad warning light - can become a franchised dealer task. This means that the independent sector, supplying parts, salvaged components and non-franchised servicing have to equip themselves, at significant expense, to be able to interface with each manufacturer's diagnostic software.

It is likely that, when reviewing the history of motoring in the 21st century, the electronic control unit will still be one of the 10 most significant objects in that history but the consumer's choice of repairer may look very different from today.

Postscript: The earlier 'Prior Art' panel focuses on the Alldays & Onions 1911 Victoria on display in the Cotswold Motoring Museum. It is probably fair to say that, to most of us, the manufacturer's name is not a familiar one. Like many carmakers from the early 20th century, Alldays & Onions came from a varied manufacturing background. Cycles, motorcycles, production tools and ventilation equipment were all part of the company's product range before and after the addition of cars and commercial vehicles. Norman Painting has produced a fascinating history of the company (which still exists today as Allday Peacock & Co Ltd) covering the period in which the 1911 Victoria was produced.

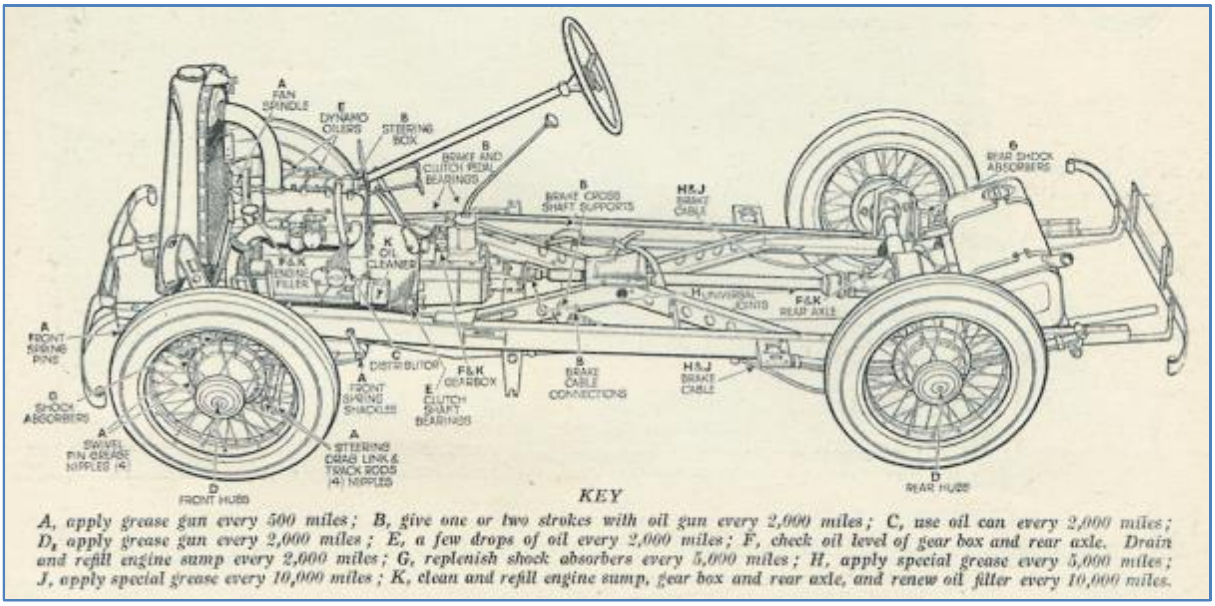
NOTE: To avoid any possible confusion, followers of the BBC series, The Archers, will recognise the coincidence of the name of Norman Painting who played the role of Phil Archer for 59 years and was also an author of books on 'Ambridge'. He was not however the same Norman Painting who is an authority on Alldays & Onions!



Picture Captions and Credits

The assistance of RAC Technical Training Department is gratefully acknowledged for providing the ECUs shown in this chapter and for display at the Cotswold Motoring Museum &Toy Collection

Page 20: Siemens engine management unit from a Renault
Page 22: 1911 Alldays & Onions Victoria on display at the Cotswold Motoring Museum & Toy Collection
Page 22: Sun and Crypton diagnostic equipment on display at the Cotswold Motoring Museum & Toy Collection
Page 23: Typical location for the engine management ECU
Page 26: Cover image "Alldays & Onions - A Brief History" by Norman Painting, Landmark Collectors Library, 2002



The picture above is from the 12 April 1935 issue of Autocar magazine and is part of an article on the service and care for a 1935 Standard Nine. It also provides an excellent view of what is now known as a car's powertrain. For a modern, rear-wheel drive, internal combustion engine car, all the essential components of the powertrain would be readily identifiable from this 80-year-old picture.

The main components of the powertrain are the engine, gearbox (or transmission) and differential (or final drive). A more rigorous list would include the clutch ([torque converter]() for an automatic gearbox), propeller shaft, universal joint(s), drive shafts, rear hubs (or constant velocity joints for front wheel drive), wheels and tyres. The term drive train is also used, although strictly speaking this should refer to the powertrain, less the engine.

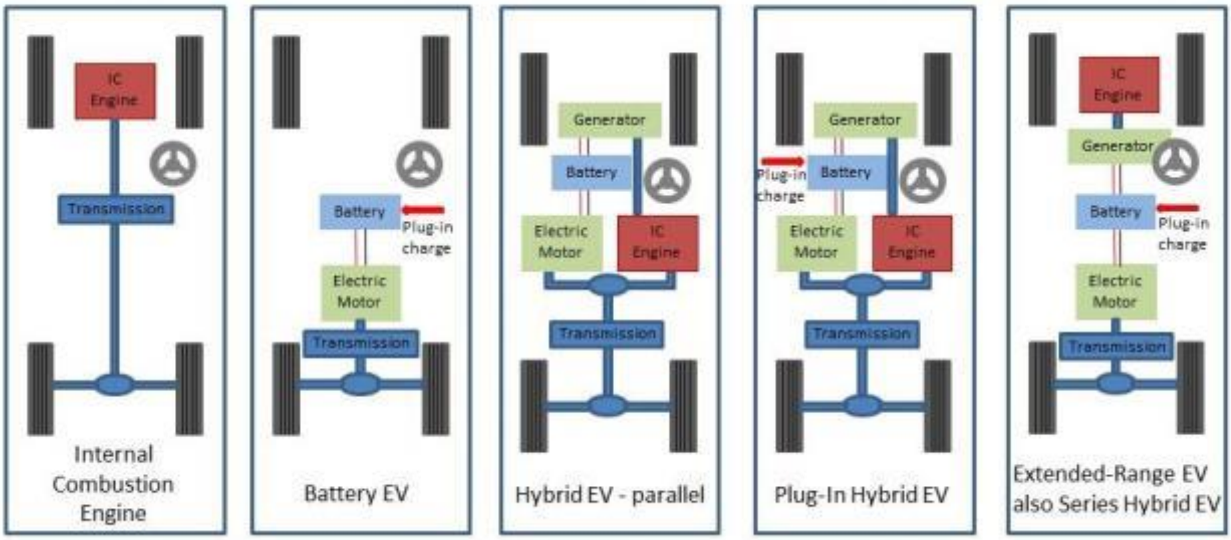
For a front-wheel drive, internal combustion engine car the powertrain would look very different but, with the exception of the propeller shaft, would comprise the same list of components. A four-wheel drive car requires a front, rear and centre differential to distribute power to the four wheels whilst a hybrid electric vehicle would have a [powertrain]() that looks quite unlike the 1935 picture.

Some of the basics however have not changed since the 1935 Standard Nine was designed. The car's speed per engine revolution (often quoted at an engine speed of 1000rpm) will depend upon the gearbox ratio in each gear, final drive ratio and wheel and tyre rolling circumference. Choice of materials, low-friction coatings and specialist lubricants for engine, gearbox and final drive will affect the overall efficiency of the powertrain.

The aim of any powertrain design is to balance a range of (often conflicting) performance criteria. These include top speed, acceleration, fuel consumption, exhaust emissions – all of which depend, amongst other things, on the weight of the powertrain components - as well as serviceable lifetime and both production and lifetime costs. Powertrain designers work in close cooperation with body stylists - aerodynamic performance is a major factor in the overall efficiency of the car - with computer modelling being the starting point of any design process.

In addition to computer modelling skills, design of the powertrain for a modern car involves specialist mechanical, electronic and chemical input plus a good understanding of materials science. It is very much a cross-disciplinary task.

In recent years, powertrain design has seen a resurgence with the advent of hybrid electric vehicles. Electric vehicles are the subject of the following chapter but, for the purposes of powertrain design, it is informative to consider the relative merits of Battery Electric Vehicles (BEV), Hybrid Electric Vehicles (HEV), including plug-in hybrid electric vehicles (PHEV), and Extended-Range Electric Vehicles (E-REV). The following schematic drawings show these basic configurations. To retain focus on powertrain, these drawings are very simplified. No



regenerative braking is shown, super-capacitors and supplementary batteries are omitted along with any references to power conditioning electronics, ECUs and on-board battery charging components. Also, in some configurations, a single electric motor may be replaced by one at each driven wheel.

On the road, cars of competing powertrain designs have been ranged against each other in the RAC Future Car Challenge. The real-world environment is, in fact, the route from Brighton to London, including sections of motorway, urban and suburban driving. Entry is restricted to cars emitting less than 110g/km of CO_2: which, of course, allows some internal combustion engine cars to compete, making for an interesting competition. Events were held in 2010, 2011 and 2012.

A paper published on the 2012 challenge[7] measured the total energy used by all the configurations of powertrain design shown above. Electrical energy used during the challenge was logged in the car and (where relevant) brim-to-brim measurements of fuel consumed were converted into energy used through well-established conversion factors for petrol and diesel fuel. The challenge was to complete the course using the least amount of energy and, maybe

[7] "The 2012 RAC Future Car Challenge: The Impact of Hybridisation on Energy Consumption", von Srbik et al.

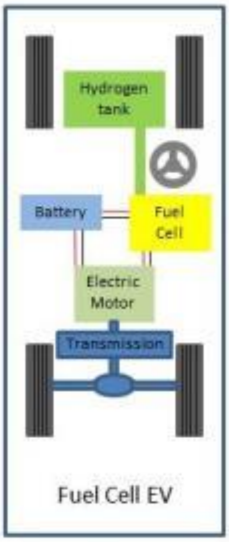
not surprisingly, the lightest BEVs proved to consume the least energy, followed by the Plug-In Hybrid EV and finally the Internal Combustion Engine car.

To allow for variations in weight between the vehicles, the measure of energy used throughout the challenge was expressed as Watt-hours per kilometre per kilogram of car weight (Wh km^{-1} kg^{-1}). When weight was included in the calculation of efficiency, the heavier vehicles were relatively more efficient with the Plug-In Hybrid EV giving similar performance to the BEV.

The 2011 winner of the challenge was the BEV produced by Gordon Murray, the T.27. In 2012, the first and second places were taken by prototype cars but third place overall went to a production car, the Renault Zoe EV with three prototype Jaguar XJ cars (E-REV/PHEV) coming 11th to 13th in a field with 33 finishers.

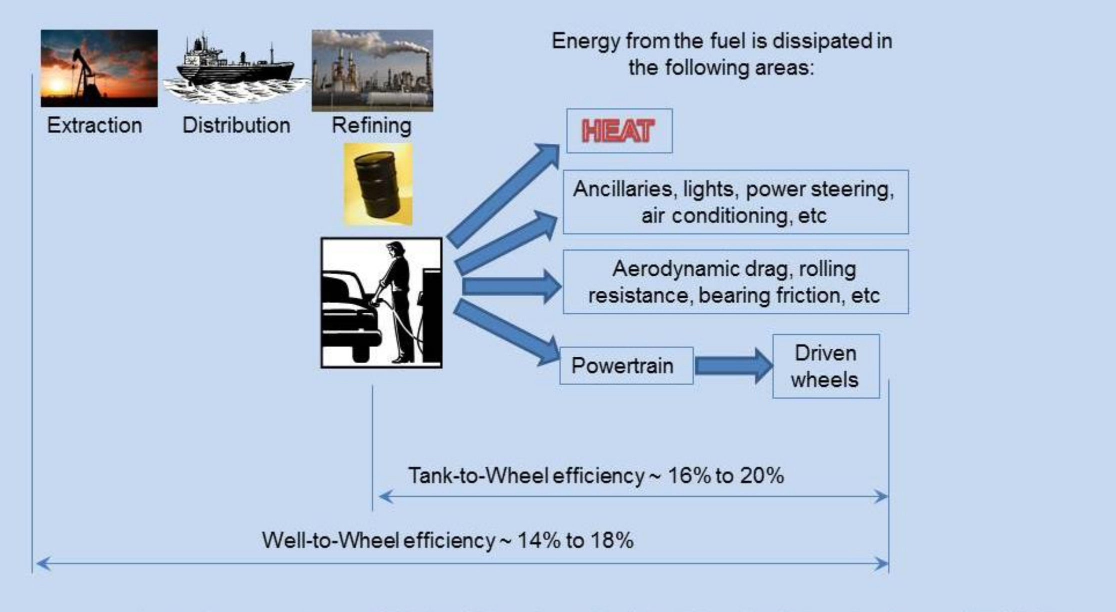
In 2014, one of the best examples of powertrain development was in the world of Formula One racing. Rule changes meant that the 2013, 2.4 litre V8 engine had to be replaced with a 1.6 litre turbocharged V6 and two Energy Recovery Systems (ERS) replaced the earlier Kinetic Energy Recovery System (KERS). In addition, unlike KERS, which was activated by the driver for a few seconds each lap, the ERS had to be available for over 30 seconds per lap and was activated solely through use of the throttle: in other words, much more akin to how a road car would use recovered kinetic and heat energy. The power outputs from the internal combustion engine and the ERS are around 600bhp and 160bhp respectively.

In 2013, UK registrations of hybrid and plug-in cars (ie BEVs, PHEVs and E-REVs) totalled 32,715. Of these, plug-in vehicles accounted for just 11%. This may, in part, be down to availability, with cars such as the Toyota Prius, a HEV, being firmly established in the market whilst plug-in and BEVs were later to market or it may be an indication of the motoring public's preference for energy recovery and an internal combustion engine to take over when batteries need recharging. Plug-in after all is not too easy when the car is parked at the roadside.



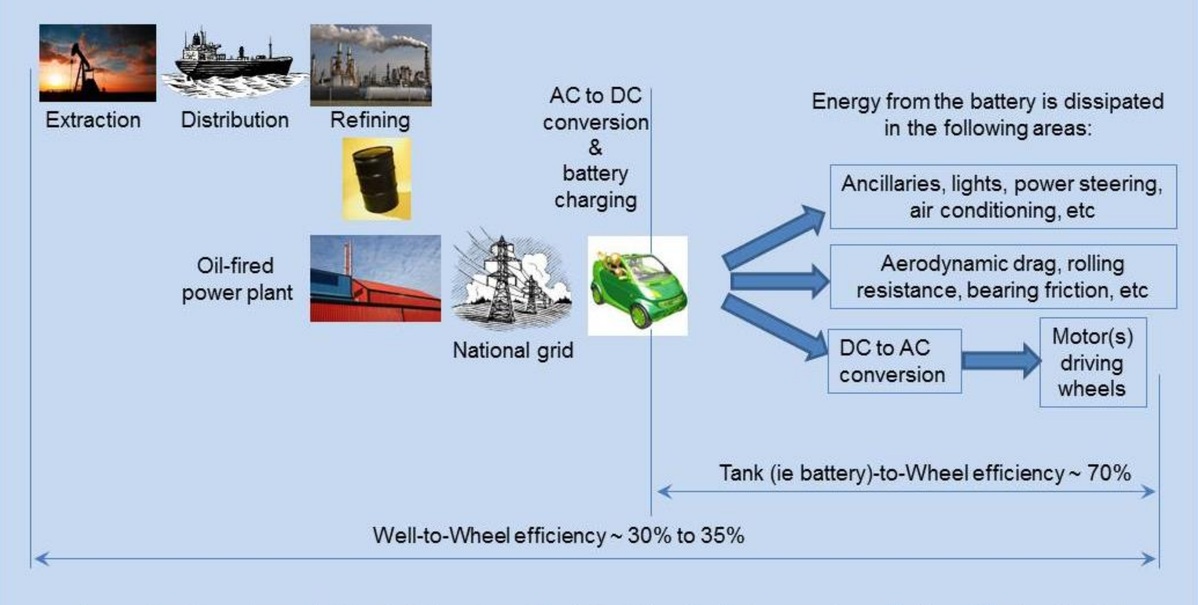
Finally, the fuel cell electric vehicle (FCEV) has been under development for more than a decade. A very simplified schematic is shown here with ancillary components associated with voltage conversion and regenerative braking omitted. This does not require a plug-in but it does require a hydrogen infrastructure which today, is conspicuous by its absence.

A fleeting reference was made to powertrain efficiency in the opening paragraphs of this chapter. A figure of [15% tank-to-wheel efficiency] was also previously mentioned as typical of an internal combustion engine powered car. This figure represents the fraction of the energy



Approximate values of Well-to-Wheel and Tank-to-Wheel efficiencies for an ICE Vehicle
(figures will differ between cars and will be dependent *inter alia* on weather and driving conditions)

stored in the fuel that is used to propel the car. The drivetrain of a modern electric car has far fewer moving parts than its petrol or diesel powered equivalent, emits much less heat and can achieve a 'tank' (ie battery) to wheel efficiency of around 70%. This is not quite a valid comparison since the energy stored in the battery of the electric car is derived from the national power grid with its mix of generating capacity, including fossil fuel. When the efficiency of power generation and distribution is taken into account, the tank-to-wheel efficiency of the electric car is more like 33%: still a significant improvement over the petrol / diesel counterpart.



Approximate values of Well-to-Wheel and Tank-to-Wheel efficiencies for a Battery Electric Vehicle
(figures will differ between BEVs, will be dependent on weather, driving conditions and power generator mix)

When including the energy used in extracting and distributing the fuel to be burnt in either the internal combustion engine or the power generation infrastructure, the respective well-to-wheel efficiencies of electric and internal combustion become, approximately, 30% and 14% respectively.

Which of the powertrain configurations presented above will dominate as the 21st century evolves is still an unanswerable question. Motor manufacturers are investing heavily in all of the options with legislation a major driving force for CO_2 reduction: an area where the BEV is a strong contender.

One thing that is certain is that the service and care of the 21st century powertrain will be very different from the service and care of the 1935 Standard Nine at the start of this chapter.

Picture Captions and Credits

Page 27: Autocar 12 April 1935
Page 29: Gordon Murray T.27 BEV: http://www.gordonmurraydesign.com/previous/press-T27-unveiled.php
Page 29: Renault Zoe from the Green Car Website:
http://www.thegreencarwebsite.co.uk/blog/index.php/2012/11/05/renault-zoe-wins-rac-future-car-challenge/
Page 30: Well-to-Wheel diagrams use Microsoft Office clip Art throughout

Part 3 - Technological | Electric Vehicles

Are electric vehicles going to be the success story of motoring in the 21st century?

Fossil fuel, both liquid and gas, is coming into competition with battery power, hybrid vehicles, hydrogen-powered fuel cells and even solar power. Will the 21st century see just a single winner? These fuels and their associated environmental impact are outlined in this chapter.

Introduction

Electric vehicles have been around since the dawn of motoring. As early as 1835, Thomas Davenport, a blacksmith from Vermont, built an electric car and in 1899, an electric car held the world land-speed record at 66mph. Today's land speed record for an electric car, set in June 2013, is 204.18mph and 2014/15 will see the launch of Formula E, the all-electric version of Formula One, staged in 10 world cities and finishing in London in June 2015.

Even within today's minority market for electric vehicles, the battery powered car and hybrid face challenges from cars powered by hydrogen fuel cells and solar. Meanwhile, the mature technology of the internal combustion engine powered car has been rapidly advancing. Using lower weight materials, electric rather than hydraulic actuators and improved combustion, the fuel consumption and CO_2 emission figures of the average family saloon from just a decade ago look very poor when compared to today's performance.

The recent popularity of electric vehicles for urban use in cities such as Oslo, where nationally there are over 21,000 electric vehicles in a population of 5 million, can be heavily influenced by government and city incentives. What happens when these incentives are removed, as will inevitably happen one day?

There is also the consideration of how the electricity to recharge the electric car is generated. If generated from fossil fuel, there is the argument that whilst the dense urban environment may benefit from lower atmospheric pollution, the overall contribution to atmospheric gases is simply shifted from the city to the site of the generator.

This chapter seeks to shed light on some of these issues.

Battery Power

The Waverley electric car, shown here at the start of the London to Brighton run, was manufactured in the United States in 1903 and remains capable of travelling from London to Brighton on a November Sunday morning, carrying 3 adults, with just a couple of re-charging breaks.

Between 1950 and 1970, in the UK, electrically powered vehicles found a niche where the limitations of speed and distance imposed by battery operation were no great barrier to their role. Used as 'yard' vehicles, for the delivery of milk, they returned to a central depot for an overnight recharge and ran around well-defined, urban routes. They were quiet, suiting their early morning deliveries; it was just the bottles that were noisy!

Over more than 170 years, the issue of battery life and hence distance covered between battery charging, has been dominant. In more recent times, environmental concerns over fossil fuel use, accompanied by new battery technology (such as lithium-ion), government subsidies, plus tax and congestion charge advantages, mean that electric vehicles are being seriously marketed as alternatives to internal combustion engine cars and light vans.

Today, at least for short urban journeys, battery powered vehicles are becoming technically, operationally and financially feasible. A National Household Travel Survey in the USA showed an average daily commuting trip length of 12.4 miles. Also, 95% of journeys are less than 40 miles and 99% less than 60 miles. Even on the most pessimistic estimates of range, this puts those journeys within the capability of most electric vehicles on the market today. UK commuting appears to be similar. Based on Department of Transport figures, the UK average commuting trip length in 2012 was 9 miles.

The various configurations of electric vehicle (EV) and hybrid electric vehicle (HEV) are tabulated later in this chapter. In many configurations, the drive to the wheels is via an electric motor, which draws its power from an on-board battery pack. These batteries may be charged by a small on-board internal combustion engine or by simply connecting the vehicle to a mains power supply. For a normal domestic supply, they usually require an overnight charge to restore maximum capacity. A feature of most modern electric cars is the regenerative braking system, which allows the battery or a capacitor to be topped up with energy generated during braking.

Returning to the 'yard' vehicle, this time in a public transport role, an approach to top-up recharging is undergoing trials on a fleet of eight electric buses in Milton Keynes. At the end of their 15-mile route, the buses park over a pad in the roadway and lower a corresponding pad on the bus. These pads contain electric coils and the bus battery recharges via a current induced into the bus coil from that in the roadway. A 10-minute top-up during the driver's break restores two-thirds of the energy expended during the previous 15 miles. An overnight charge from the mains is necessary during the 7 hours a day that they are off the road.

For the privately owned battery powered car, the slow growth in numbers on the UK roads arises from a number of factors. These include an initial high purchase price, limited range on a battery charge, giving rise to so called 'range anxiety', few public charging points and a lack of standardisation of the charging connector. Particular stress is placed on the battery in cold, dark conditions. Performance falls with decreasing temperature and in these circumstances it is also likely to be providing not only the energy for propulsion but also powering the lights, heater, wipers, radio, etc. As an indication of progress, however, the Tesla electric sports car with a range of over 200 miles, is as far removed from the electric milk float of the 1950s or the Waverley of 1903 as it is possible to imagine.

Returning to the world land-speed record for a light electric car (less than 1000kg), this was broken in June 2013 by a converted former Le Mans Lola racing car that achieved an average speed of 204.18mph. Technology drivers such as this and the technology spin-off from Formula E cars, such as light-weight materials and tyre technology, can only benefit the prospects of future battery powered cars.

Fuel cell electric vehicles

A fuel cell is an electrochemical, energy conversion device. A fuel cell converts the chemicals hydrogen and oxygen into water, and in the process it produces electricity. Electricity can be produced constantly as long as the flow of chemicals continues. Fuel cell technology has been under development for many years but is currently still expensive in comparison with battery technology. Hydrogen production, for example through electrolysis of water, requires energy and unless this is derived from renewable sources, the overall carbon dioxide production associated with hydrogen propulsion may not be as little as first appears. Significant research funding is addressing cheaper and lower carbon techniques for hydrogen production from water. Solar powered, high temperature techniques and ambient temperature techniques using an affordable cobalt catalyst are two current research areas. Transportation of compressed hydrogen gas or liquid hydrogen is also an inefficient process, as typically, 99% of the transported load comprises the weight of the delivery vehicle.

A fuel cell electric vehicle (FCEV) has no internal combustion engine and, with the exception of the Audi battery hybrid model (see below), does not need to be recharged from the mains. Many manufacturers have already demonstrated fuel cell vehicles and there are some currently in use providing important information and feedback for the future development of FCEVs. Technical challenges include:

- safe storage of hydrogen in the car. Compressed hydrogen gas – at a few hundred bar - rather than liquid hydrogen, is likely to be stored in carbon-fibre reinforced tanks

- production, distribution and storage infrastructure for hydrogen
- reliable use in cold weather
- reduction in cost through minimising the use of the expensive catalyst, platinum

At the time of the 2012 London Olympics, a number of hydrogen fuelled London taxis were used to ferry VIPs around the Olympic venues. The cab has a top speed of 80mph and a range of more than 250 miles on a full tank with refuelling taking approximately five minutes.

At the 2014 Los Angeles motor show, Audi revealed a plug-in hydrogen hybrid capable of operating with the fuel cell only, fuel cell and battery or battery only. The hydrogen fuel cell is claimed to provide a further 342 miles range once the battery-only option is exhausted. At the same show Toyota unveiled their Mirai, a production-ready FCEV with a claimed 300 mile range.

Solar power

Using solar energy to charge an electric vehicle, when at home or at a public or work place charging point, is a step towards an overall reduction in the gaseous emissions associated with the internal combustion engine. The definition of a solar car, however, is an electric vehicle powered by energy obtained from solar panels *directly on* the car. At best, for practical cars, the solar energy can be considered as a top-up to the mains energy used for battery charging or for powering accessories such as air conditioning. Insufficient power can be generated by current solar panels on the roof of any practically sized and shaped vehicle to provide adequate performance. The Ford solar concept car, the C-Max Solar Energi, displayed at the 2014 Consumer Electronics Show, has a roof covered with solar panels but even a day in full sun is insufficient for a full recharge of the car's lithium battery. As 'technology demonstrators', solar cars are raced in competitions such as the World Solar Challenge and the North American Solar Challenge. Such challenges are used by universities to develop their student's engineering and technological skills as well as by motor vehicle manufacturers such as GM and Honda.

Electric vehicle summary

A number of configurations in which electrical power is used to propel the vehicle are emerging onto the global car market. Some of these are summarised in the table below.

Vehicle type	**Configuration**	**Examples in or nearing production**
Hybrid (HEV)	Battery powered electric motor and petrol engine (rarely a diesel due to weight) providing motive power. Batteries recharged from engine during driving and through regenerative braking. No need to plug into a charging point.	Toyota Prius (89g/km)

Vehicle type	Configuration	Examples in or nearing production
Plug-in Hybrid (PHEV)	Battery powered electric motor and petrol engine (rarely a diesel due to weight) providing motive power. Batteries recharged via a mains power connection and through regenerative braking. Permits larger battery capacity and hence a longer all-electric range than the HEV.	Toyota Prius Plug-In (49g/km) Mitsubishi Outlander (44g/km) BMW i8 (49g/km)
Extended-Range Electric Vehicle (E-REV)	Wheels always powered by an electric motor. Batteries recharged by plug-in and an on-board petrol IC engine. Electric only range 25 to 50 miles, overall range up to 360 miles.	Vauxhall Ampera Chevrolet Volt (27g/km)
Battery Electric Vehicle (BEV)	Battery powered electric motor with batteries recharged via a mains power connection. Typically 80 to 110 mile range (over 200 for the Tesla) before a recharge is required.	Renault Fluence ZE Nissan Leaf Tesla BMW i3
Fuel Cell Electric Vehicle (FCEV)	Wheels always powered by an electric motor. For the fuel cell / battery hybrid, the motor is powered by lithium ion batteries and by energy from a hydrogen fuel cell. London Taxi for 2012, Honda production by 2015, Hyundai production of 10,000 in 2015.	Honda FCX Clarity London Taxi Hyundai ix35 Audi A7 hybrid

In the luxury vehicle category is the Jaguar Limo-Green (120g/km), another example of an Extended-Range EV. In this vehicle, the wheels are driven by the electric motor and a 1.2litre, 3-cylinder petrol internal combustion engine charges the batteries. In addition, the car can also be plugged into the mains and the batteries charged overnight. For further information, see the Green Car Website.

The wider picture

Zero polluting emissions from a battery or fuel cell powered vehicle are clearly good news for people coexisting with these vehicles in a congested urban environment. However, the stored energy in a battery is replenished through recharging and this is not necessarily a pollution-free process. There is an argument that suggests the harmful emissions are just shifted from one place to another rather than being reduced.

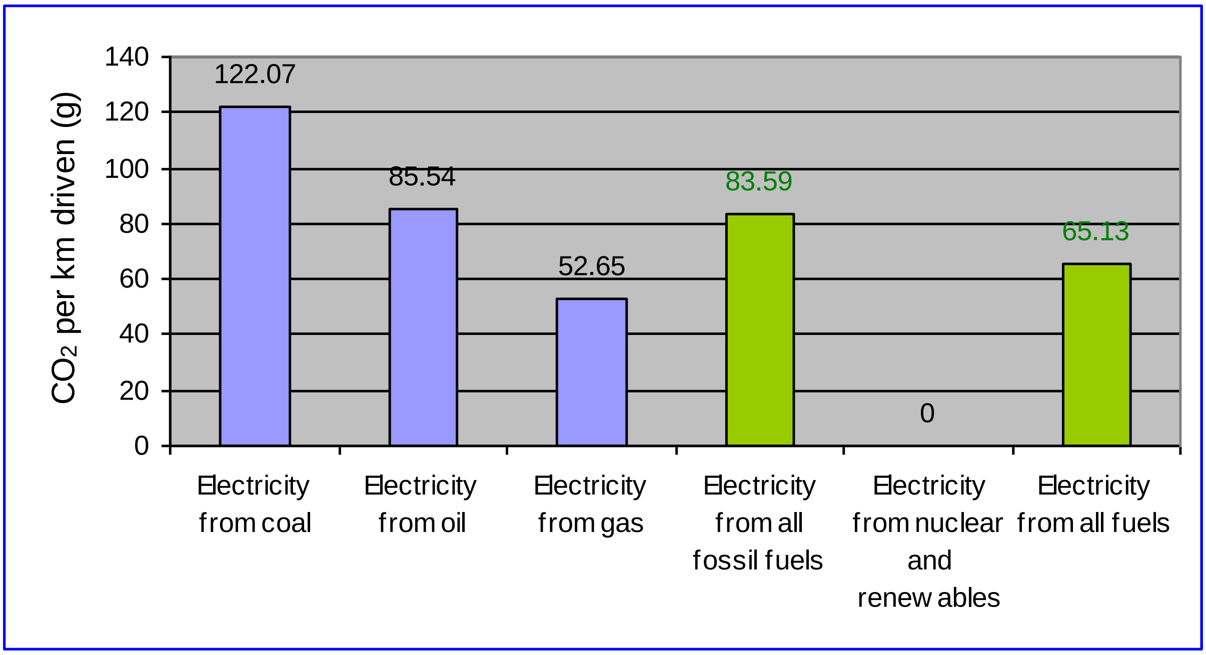
For the solar powered demonstrator vehicles mentioned above then strictly, just in terms of energy use (ignoring factors such as diminishing availability of raw materials), the energy equation should include terms reflecting the energy used in the solar cell production and end-of-life disposal balanced against the energy produced by the cells during the vehicle lifetime. For hydrogen-powered vehicles, the energy used and associated emissions in hydrogen production and transportation will offset the zero CO_2 emissions at the tailpipe. For a battery-powered vehicle, the energy used to manufacture, transport and recharge batteries throughout their life should be reflected in the overall environmental impact of the vehicle.

Quantifying the overall lifetime CO_2 budget for an electric vehicle should reflect the energy consumed in production, distribution and disposal of the whole vehicle as well as during operation. However, very different conclusions can be reached depending upon the assumptions made. A Low Carbon Vehicle Partnership report provides a good source of reference and a standard for calculating the CO_2 contribution over a vehicle's lifetime. Ozzie Zehner, a University of California professor, writing of "Green Illusions" contributes a more controversial opinion on the scientific rigour behind frequently quoted electric vehicle environmental performance.

Once on the road, from an environmental point of view, battery recharging, or hydrogen production, using electricity from a renewable energy source is clearly more environmentally friendly than charging using electricity generated from fossil fuels. Coal, oil, gas, nuclear, biomass, hydro, wind or other renewable power generation for recharging batteries will determine the effective, overall carbon dioxide emissions of each vehicle configuration.

Charging the batteries of an electric vehicle from a renewable power source, such as wind energy, will result in zero overall CO_2 emission throughout the car's journey. However, most power used to recharge the batteries of an electric vehicle is derived from a power grid fed by a mixture of coal, oil, gas, nuclear and renewable power plants. When taking into account the CO_2 emissions created in the generation of electricity, a 2009 submission by the Institution of Engineering and Technology (IET) to UK government on renewable energy has shown that the equivalent CO_2 emissions of an electric vehicle can be comparable with those of a modern petrol or diesel vehicle.

The diagram below is derived from data in the IET submission. The 'green' bars are the average of the preceding values and represent the current mix of coal, oil, gas, nuclear and renewable in UK power generation.



The CO_2 limit for exemption from the London congestion charge reduced on 1 July 2013 from 100g/km to 75g/km. A battery electric vehicle, recharged from the UK grid, has an effective CO_2 emission figure of around 65g/km. It is therefore appropriate that battery electric vehicles are exempt from the London congestion charge. In addition, the Chevrolet Volt and Vauxhall Ampera (both specified as 27g/km) and the Toyota Prius Plug-In Hybrid (specified 49g/km) are exempt from the charge.

For comparison, along with many small cars, some medium sized cars such as the 2013 VW Golf 1.6 TDI petrol and diesel saloons achieve 98 or 99g/km. The 1.1 Hyundai i20 diesel achieves 84g/km. Currently no petrol or diesel vehicle can meet the 75g/km limit.

Conclusion

Finally, returning to the whole life cycle CO_2 budget, for electric vehicles, with batteries re-charged from the UK grid with its current mix of coal, oil, gas, nuclear and renewables, the *lifetime* CO_2 will most likely be less than that of the equivalent internal combustion engine powered car but the percentage of CO_2 produced during manufacture is likely to be higher.

In summary, the Low Carbon Vehicle Partnership report states:

"……… results show hybrids and EVs [electric vehicles] will have lower life cycle CO_2 emissions, but embedded emissions [ie during manufacture] will be more significant"

and

"The technology evolution to plug-in vehicles will lead to higher embedded CO_2 emissions due to the addition of new components"

Picture Captions and Credits

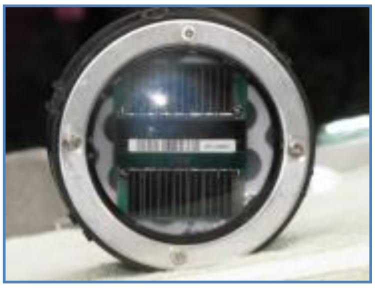
Page 32: Electric car public charging points
Page 33: 1903 Waverley electric car at the start of the 2003 London to Brighton run.
Page 33: Electric Milk Float http://www.milkfloats.org.uk/spmf2.html
Page 34: Tesla Roadster http://www.teslamotors.com/en_GB/roadster
Page 35: http://www.worldsolarchallenge.org/about_wsc_2013/photo_highlights/day_1_action

Part 3 - Technological | Safety

The wheel rim of the London to York stagecoach and that of the first petrol engine car were remarkably similar. At best, a band of solid rubber may have been laid over the iron tyre of the car wheel. The fact that the footprint of the car on the road comprises just four small contact areas between rubber and tarmac has been the driving force for 125 years development of the pneumatic tyre. The aim of that development has been to improve ride comfort, reduce noise level, reduce wear rate and, above all, to enhance the safety of the car occupants through good grip under all weather conditions.

Throughout the history of motoring, manufacturers have sought to attract buyers to their products through emphasising various aspects of their products. These have included performance, economy, aesthetics, environmental friendliness and safety. The advent of the seatbelt was one such occasion when, particularly in the USA, safety formed a major pitch in car advertising. Some manufacturers have successfully built a brand recognition that revolves around a body designed for safety and, during the 1970s, much of this association started with the seatbelt.

Recognising that the safety of vehicle occupants depends not just on the vehicle construction and maintenance but also on driver behaviour and the road network itself, an EU directive aims to halve the number of deaths on EU roads by 2020 and move close to zero fatalities by 2050.



Selecting just one aspect of the environment in which the car operates, the “Catseye”, was chosen as one of the Cotswold Motoring Museum’s “10 Objects” for the 2012 special exhibition and continues to be a feature of the museum display.

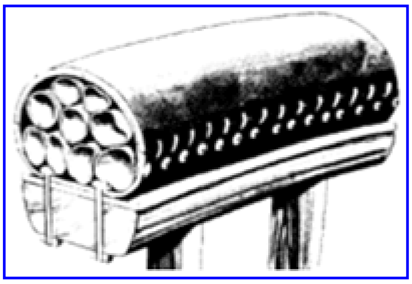
These four topics, tyres, the seatbelt, the car body and the ‘Catseye’ form the chapter headings of this section on car safety.

The Dunlop Tyre

This chapter outlines some inventions and developments that have led us to the car tyres that we today take for granted. Like many great inventions, the men with the original ideas, those remembered by history, are not necessarily the ones who saw the greatest benefit.

Introduction

The person most commonly associated with the invention of the pneumatic tyre is John Boyd Dunlop (1840 – 1921). John Dunlop was born in Ayrshire, Scotland, qualified as a veterinary surgeon and moved to Belfast in 1867. It was in 1888 whilst trying to make a more comfortable cycle tyre for his son, by wrapping an inflated tube of canvas around the wheel rim, that his idea of a pneumatic tyre was conceived and patented. After a local cyclist enjoyed competitive success through adopting Dunlop's idea, the patent was purchased in 1896 by William Harvey du Cros. At this time, Harvey du Cros was working in Dublin with John Dunlop producing pneumatic tyres for bicycles. Following the purchase of the patent, Harvey du Cros became a founder and Chairman of the Dunlop Pneumatic Tyre Company in 1896 and went on to successfully develop and exploit the manufacturing process for the pneumatic tyre.



There is however an earlier, legitimate claim to the invention of the pneumatic tyre by fellow Scotsman Robert William Thomson. Thomson was granted a patent in France in 1846 and in the USA in 1847. Thomson's "Aerial Wheels" as they were known, were demonstrated in London's Regent Park in March 1847 and were fitted to several horse-drawn carriages, greatly improving the comfort of travel and reducing noise. Frustrated by the poor availability of thin rubberised canvas tubing to fit inside a leather outer casing, he abandoned his attempts to build on his early success with inflatable tyres for horse-drawn carriages. He devoted his subsequent effort in this area[8] to the development of solid India-rubber tyres for road steamers[9] and the new omnibuses. He is remembered in his home town of Stonehaven by a bronze plaque, presented to the town in 1922 by the Royal Scottish Automobile Club which reads:

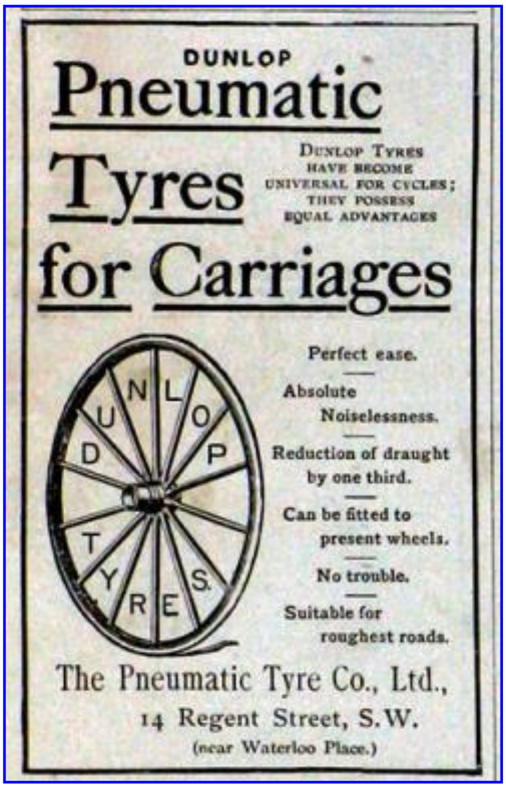
The Birthplace of Robert William Thomson
The inventor of the pneumatic tyre
Born 29th June 1822
Died 8th March 1873

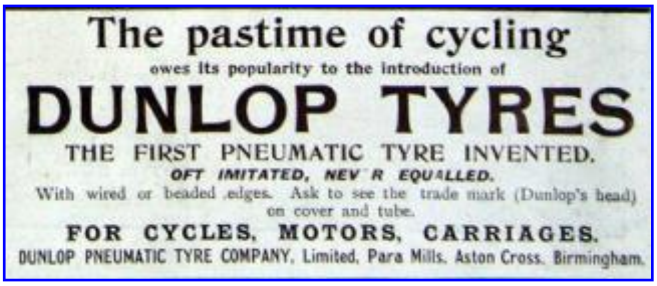
In spite of the granting of the Dunlop patent in 1888, in 1890 he was officially informed that it was invalid as Thomson's patent had preceded it. As with many inventions though, it was not the initial inventor who reaped the benefit but the individuals who exploited the idea and turned it into an affordable product capable of mass manufacture.

It was in 1900 that Dunlop began the manufacture of car tyres. Initially production was subcontracted but by 1902 it went into production in its own right at its subsidiary company the Dunlop Rubber Co. Ltd which was located at Manor Mills, Aston, Birmingham. The business relocated in 1916 to larger production facilities in Birmingham called 'Fort Dunlop'. It continued here until the late 1980s and after standing empty for 20 years, the property, alongside the M6 near junction 5, is now redeveloped into commercial and residential property. At its height, it was the world's largest factory, employing over 3200 people under one roof and, by 1955, producing almost half of all tyres sold in the UK.

Although it appears that the Dunlop Company made rapid progress following the re-invention of the pneumatic tyre in 1888, it was not Dunlop but André and Edouard Michelin, two agricultural engineers from Clermont-Ferrand, who produced the first pneumatic automobile tyre in 1895. Dunlop patents in 1893 and 1894[10] continued to focus on pneumatic tyres for "velocipedes and other vehicles": perhaps showing a lack of realisation that, in the near term, high volume production lay with automobile tyres?

[8] Thomson's inventions were not confined to rubber tyres; a list is shown at the Stonehaven hyperlink
[9] Steam powered vehicles independent of the rail network
[10] Patents GB10850 and GB11820





These two advertisements for Dunlop, from the Vintage Garage website, are dated 1896 and 1902 and do suggest that maybe the focus is still rather too heavily on carriages and cycles. Meanwhile the 1903 Notice used in Dunlop advertising also suggests that they were well aware they were in a commercial battle!

NOTICE.

It has come to our knowledge that Messrs. Michelin et Cie., of Paris, are making arrangements to put upon the market in England motor tyres manufactured according to a design which has been examined by us and our advisers.

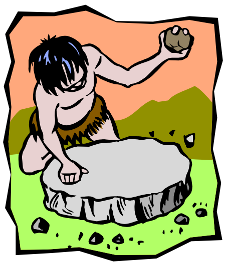
The Motor Trade and public generally are warned that proceedings will at once be taken against all Persons, Firms, and Companies, selling or using any such tyres in Great Britain, as in our opinion they infringe our well-known Letters Patent.

The Dunlop Pneumatic Tyre Co., Ltd.,
14, REGENT STREET, LONDON.

On the left below is the tyre of a 1900 Napier, produced in Tenterden in Kent, which now runs on pneumatic tyres. However, when 'discovered' in 1944, it was on solid rubber tyres. In contrast the 1903 French built De Dion Bouton (right), described as "very original" started life on pneumatic tyres. Notice, in both cases, the majority of the wheel is constructed from wood.

The Prior Art

It is claimed that the origin of the word “tyre” derives from the wheelwright’s habit of referring to the steel rim around a wooden spoked wheel as the item that ‘tied’ the wheel together. Hence a tyre! Before moving on to look at the composition and usage of modern pneumatic tyres, it is worth briefly considering life before the inflatable tyre. The image to the right shows a chariot found in the tomb of King Tutankhamen dating from 3300 years ago. The wheels have no tyres!



In Monteleone, on the Swiss / Italian border, 2600 years ago, a chariot was mislaid and it was not until 1902 that it was rediscovered. The chariot, from an ancient Italian civilisation (Etruscan) was found along with other bronze, ceramic and iron items as if placed in a burial mound. It is one of the best-preserved finds from before the Roman period and is now in the Metropolitan Museum of Art in New York. The photograph on the left is a reconstruction but significant, major parts of the original chariot were in relatively good condition. This included one wheel, which was riveted with bronze and fitted with an iron tyre. Fundamentally, the technology of wheel construction and the materials used continued, largely without change, for nearly 2500 years; the images below are from the most recent part of that long period.

The left-hand image shows, the iron-tyred wheel of a London to York mail coach. Coaches reached their heyday in the late 1700s before being displaced by the railway; the pioneer of which was the wooden-wheeled, iron-rimmed 1829 Stephenson’s ‘Rocket’ locomotive (centre). Whilst early cars, such as the French-built, 1895 Panhard and Levassor car, used wooden wheels and an iron rim covered in solid rubber (right).

The use of rubber in road transport and other industries is outlined in the following section.

The key to developing a hardwearing rubber cushion between the iron rim of a wooden-spoked wheel and the road surface lay with the American inventor Charles Goodyear. In 1839, Goodyear (and, independently, Thomas Hancock in Britain) developed the process of vulcanising rubber: a process that transformed an interesting, natural latex into a resistant, elastic material that was showcased in the Great Exhibitions of London (1851) and Paris (1855). Applications on show included use as a solid rubber tyre for coaches.

Rubber[11]

Materials that in everyday conversation we may refer to as being made from "rubber" can be broadly divided between those derived from natural rubber and those produced from synthetic rubber; as well as mixtures of the two. Natural rubber, also known as India rubber, is produced from the white liquid – natural latex – produced from cutting the trunk of some plants and trees; in particular the rubber tree (Hevea Brasiliensis) originally from the Amazonian rainforests. European awareness of rubber probably started with Spanish colonists in South America in the 17th century where its waterproof properties were exploited for clothing and footwear. In the 18th century, it was found that small balls of dried latex were good for erasing pencil marks from writing material; hence the name rubber became associated with a material that had previously been known as *caoutchouc* from the Amazonian word for 'weeping wood'.

From the point of view of tyre fabrication (and indeed other processes), natural latex has a number of undesirable qualities. In cold weather, the material becomes brittle; in hot weather, it becomes very sticky. In the 19th century, there was much experimentation in Europe and America to try to stabilise its properties. Success is generally credited to Charles Goodyear who, in 1839, discovered that by adding sulphur to latex and heating the mixture, the resulting material became stronger whilst retaining flexibility. The process became known as vulcanisation and a patent was granted in the USA in 1844.

Between 1880 and 1911, the world demand for rubber soared with the majority of the raw material coming from the Amazonian rainforests. In 1910, 2.5 million tyres were produced: by 1990 this had risen to 860 million and today exceeds 1 billion. This demand has been met in two ways. In the 1870s, seeds from the Amazonian rubber trees were used to start plantations in Malaysia and Indonesia, expanding and diversifying the sources of natural rubber, and, in addition, synthetic rubber was developed.

[11] Some of the material for this section is based on information displayed at The Eden Project, Cornwall

A rubber tree takes 7 years to mature before starting a productive life of 25 years. So, when each new area of Asian plantation matured and entered production the world price of rubber fell abruptly, such as in 1925, and this has been a continuing trend as production capability fluctuates and competition from synthetic rubber moves with oil prices. Natural rubber from Thailand, Malaysia and Indonesia now dominates the world's supply; representing around 40% of the total global rubber production.

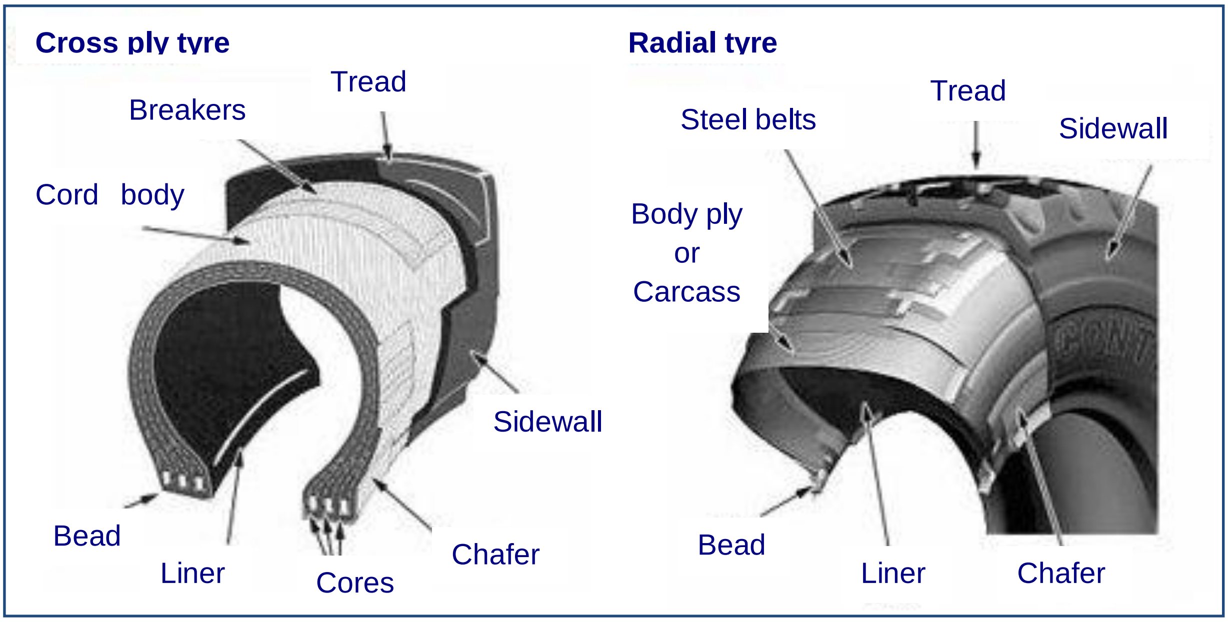
Synthetic rubber is man-made: a product of a petrochemical plant and, today, accounts for the other 60%. The development of synthetic rubber was a consequence of restricted access to natural rubber. Reasons included volatile or rising prices for natural rubber on the world market, long transport distances, the increase in global demand for rubber and, in particular, political events (such as WWI and WWII) which cut customers off from the suppliers of raw materials.

There are many compositions of synthetic rubber that vary with the end use of the material. Commonly known names such as neoprene have excellent oil and fuel resistance and are used in the automotive industry for fan / alternator / water pump belts, fuel hoses and gaskets. Butyl rubber is a common sheet material used for roofing. The modern pneumatic tyre is made up from several synthetic rubbers in specific parts of the tyre, as well as natural rubber. Carbon black is added to the rubber compound to improve wear properties. Some contain natural rubber and maize, reducing the amount of carbon black, road friction and hence fuel use. A summary of materials used in tyre construction can be found at this link and on Wikipedia.

Construction of the Pneumatic Tyre

Prior to 1924, the majority of European car manufacturers fitted wheels for use with beaded edge tyres. A hard rubber bead around the tyre's sidewalls engages in a hook or clincher on the circumference of the wheel rim and a pressure of up to 60 pounds per square inch in the inner tube is required to keep the tyre on the rim. A diagram is included at the above link. The modern wheel and tyre configuration arrived in the mid 1920's. It was a significant improvement being easier to fit and remove, much safer and needed lower pressure. This type of tyre has a wire bead which allows the tyre to sit firmly against the wheel rim, yet is fairly easy to remove by deflating and pushing the tyre rim inwards, into the well of the wheel.

Many websites show the construction of tyres. The image below shows the major parts of a cross ply tyre and radial tyre and is based on the Tyres Online website image. Perhaps surprisingly, rubber, of multiple types, constitutes only around only 40% of the weight of a modern car tyre. Steel, carbon black and fabric comprise the majority of the other 60%.



Until the 1970s, the majority of cars on European roads used cross ply tyres. These were so named because the construction of the body or carcass was based on multiple layers of rubber-coated nylon or rayon fabric cord laid across each other at an angle and moulded to metal hoops or rings that formed the tyre bead. The angle between the plies determined the stiffness of the tyre and the number of plies determined the load rating. The angle between the plies varied from around 25 degrees for racing tyres to around 40 degrees for standard tyres and the number of plies varied from 2 to 6.

Two developments in the 1940s were, ultimately, to radically change the performance of the pneumatic tyre to that which we are familiar with today. These were the development of the tubeless tyre by Goodrich in 1947 and the radial ply tyre by Michelin in 1946. A patent for the tubeless tyre was awarded in 1903 to the Goodyear Tyre Company but this was not exploited until 1947. Similarly, the radial ply tyre was patented in 1915 by Arthur W Savage but exploitation had to wait a further 30 years.

The carcass of the modern radial ply tyre is made from fine cords of material such as Kevlar, moulded into rubber and providing a major part of the physical strength of the tyre. Unlike the cross-ply tyre, these are laid across the tyre at 90 degrees to the direction of travel ie radially.

Main tyre sidewall markings

205	Width of the tyre in mm	R	Radial construction
60	Aspect ratio - the side wall height is 60% of the tyre width	15	Diameter of the wheel in inches
		91	Load index of 615kg per tyre
		V	Maximum speed rating 149mph

For a full definition of tyre markings see: http://en.wikipedia.org/wiki/Tire_code

The steel belts are fabricated from multiple cords of rubber-coated, carbon steel wire: often assembled from more than a single layer and bonded together during the curing of the tyre under heat and pressure. They provide resistance to road surface shock and a flat surface to maximise contact area with the road. A hoop of steel forms the bead: holding the tyre to the rim under the forces exerted during cornering. The synthetic rubber liner is the air-tight equivalent of the inner tube found in an earlier generation of pneumatic tyre.

Associated developments

For the last 120 years, car tyres with inner tubes as well as tubeless tyres all use the Schrader valve for inflation. This was invented by August Schrader in 1891: just as John Boyd Dunlop was starting to see the success of his pneumatic cycle tyre. The above link to Wikipedia shows a simple animation of the valve operation.

Dust cap, valve body and Schrader valve

A modern development, building on the Schrader valve, provides the car driver with a remote, real-time indication of the air pressure in the tyre. This feature may be available as original equipment with a new vehicle: either standard fit or an option and is also available as an after-market accessory. The most common configuration uses a small, battery-powered radio frequency (rf) transmitter, usually operating in a licence-exempt part of the rf spectrum, linked to the pressure sensor. For the after-market product, the rf receiver will typically display the pressure and temperature of each tyre. For the more tightly integrated original equipment, a light on the instrument cluster may illuminate to warn of a tyre pressure outside safety limits. Sensors are either used to replace the four dust caps (in the after-market role) or mounted within the tyre. An alternative, cheaper technology is based on sensing changes in wheel rotation as a tyre deflates but this is generally considered inferior to the direct sensing systems described above. Tyre pressure monitoring systems (TPMS) have been mandatory on new vehicles in the US since 2008 and will become mandatory on new cars in the EU from November 2014. From 2012 TPMS, when fitted, is subject to the UK MoT test.

A revised presentation (see Annex) of tyre performance data to the motorist purchasing a new tyre becomes mandatory from the same date.

Conclusion

There is much more that could be written about the pneumatic tyre and its future but space is limited. The pros and cons of low-profile tyres, the effect of tyre pressure on car handling, the lessons that can be learnt from the Formula One world, Goodyear's self-inflating tyre, recycling of tyres: all are worthy of more detail. But, there is one view of the future that could see the demise of pneumatic tyres. Run flat tyres have been available for some years (and certainly require use in conjunction with a TPMS) but the future may see the end of any air inside the tyre as Bridgestone make strong claims for the environmental friendliness of their 'Air-free tyre' and Michelin have been showing prototypes of their Tweel since 2005.

As this chapter has been produced in support of a display at the Cotswold Motoring Museum

and Toy Collection, it is fitting to end with an exhibit in the museum. The 1911 Alldays & Onions Victoria (left) in the museum collection is fitted with an air compressor and storage cylinder under the floor on the driver's side. Although a 1911 patent by William Allday to use compressed air to operate a pneumatic

starter never made it into production, the compressed air cylinder is connected to pressure gauges and a length of hosing within the car. In practice, this ensures the tyres are maintained at the requisite pressure of 50 pounds per square inch at all times. However, it also makes an implicit and not very subtle statement about the reliability of the pneumatic tyre and the road conditions during the early part of the 20th century!

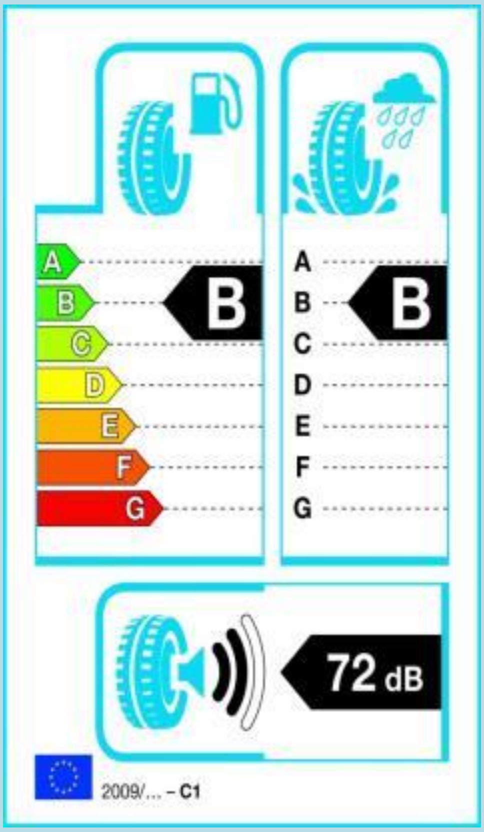
Annex: European tyre labels

New European tyre labelling - mandatory from November 2012.

Fuel efficiency is related to the rolling resistance of the tyre. The lower the rolling resistance, the lower the fuel consumption and the less the CO_2 emissions and the cost of driving. The difference between each grade means a reduction or increase in fuel consumption of between 2.5% and 4.5%.

Wet grip relates to the tyres ability to stop a vehicle quickly on wet roads and can be expressed in terms of stopping distance. The difference between each grade means an increase or decrease in stopping distance of between 3 and 6 metres when braking from 50mph.

The external noise made by the tyre is measured in decibels. The more black bars shown on the label, the louder the tyre.



Picture Captions and Credits

Page 40: Images taken at: the Eden Project, Cornwall; the Cotswold Motoring Museum & Toy Collection; the NEC Classic Vehicle Motorshow and from the website http://www.ulsterhistory.co.uk/johndunlop.htm
Page 41: Unknown credit for the drawing of Thomson's pneumatic tyre
Page 42: Images taken at the NEC Classic Vehicle Motorshow
Page 43: Follow hyperlinks for credits to chariot pictures. Inset image from the Ashmolean Museum, Oxford, shows the elm wood hub of a chariot wheel from 1350BC.
Page 43: Wheel images taken at the Science Museum, London
Page 44: Image taken at the Eden Project, Cornwall
Page 45: Image taken at the Eden Project, Cornwall
Page 46: Sidewall markings of a modern pneumatic tyre
Page 47: Schrader valve circa 1930
Page 48: Alldays & Onions Victoria at the Cotswold Motoring Museum and Toy Collection
Page 48: Montage of enamel tyre advertisements at the Cotswold Motoring Museum and Toy Collection

How did the Seat belt come to be invented?

This chapter describes the background to the invention of the seat belt. The motor manufacturers response to increasing customer concern over occupant safety and government legislation have been critical in reaching today's level of 95% seat belt usage in the UK.

Introduction

"Clunk Click Every Trip" was a safety advertisement in the early 1970s that was drummed into us, just like our kerb drill, until it became an automatic action as we settled into our car. Today, whenever we get into a car, we fasten our seat belts; at least most of us do but why? Is it simply because we know it is the law and risk a possible fine for not complying? This may be so in some cases but not the majority. Most of us, confident as we are of our own consummate skill as a driver, nevertheless recognise the danger posed by other road users less competent than ourselves and belt up just to be on the safe side. However, whose bright idea was the seat belt anyway and why is it now the law to wear one?


1959 poster showing how to use the seat belt

When visiting a motor museum, take a close look at any of those pioneering automobiles that were not so far removed from the horse drawn carriages on which they were modelled. The driver sat high up, often on a rudimentary bench seat. Roads as we know them did not exist; they drove on cart tracks often poorly constructed, potholed and badly drained. There being very few other vehicles, the danger was not from a collision but from being thrown out of the vehicle itself. For the driver this would be not only dangerous but also embarrassing; to lose a passenger was worse and considered the height of bad manners! As cars developed with more power and speed, with a lower slung chassis and more enveloping bodywork so other inherent dangers became apparent. Steering wheels pointing straight at the chest, flat windscreens directly in front of the face and other switches and fittings, were all awaiting the chance to fracture bones and tear skin of the unfortunate occupants.

From an early date, it became apparent to many that the main cause of injury resulting from a motoring collision or incident was due to the occupants being flung about helplessly inside the vehicle. Put an egg in a tin box and shake it hard; chances are the egg will be smashed. Put it in a properly constructed egg box and shake it hard; chances are it will remain unharmed. Exactly the same principles apply to the occupants of a car. In the event of a collision, the occupants are unable to control their own movements; they are flung about by the force of the impact. Should the vehicle roll over the occupant would very likely suffer head, neck and back injury, if not death. The first safety rule therefore is to restrain the occupants in the safest possible position within the vehicle: hey presto, enter the seat belt.

The history of the seat belt goes back a long way, much further than most of us would believe and many individuals and manufacturers lay claim to some of the glory in its development. All can be justifiably proud of their contribution to in-car safety if for no other reason than they cared enough to try. Even those designs that were destined to be abandoned or superseded, at least stimulated thought and development. First, let us examine briefly the different types of seat belts that have been used over the years.

Seat belt classifications

Seat belts are generally classified by the number of anchorage points and the location of the strap or straps.

1. Two point system – having two separate end anchors. Most commonly, a lap belt secured either side of the hips. This type of belt is usually found in passenger aeroplanes and long distance coaches. Whilst this type of belt allows freedom of movement, the upper torso is unprotected and the sudden violent movement occasioned by a collision would often result in serious back injury. An alternative two point system is the diagonal chest belt worn like a sash, where the belt stretches from above the outboard shoulder diagonally downwards to a fixed point below the inboard hip. Although allowing freedom of movement it was possible for the wearer to slide downwards out of the belt, a situation called “submarining”.

2. Three-point system – having three separate anchor points. This is the most common type of belt found in cars today and combines the best features of both the lap belt and the sash or diagonal chest belt; both sash and lap belts utilise a common anchor point below the hip. The earliest three point systems required two hands to secure but later development led to the single-handed operation commonplace today.

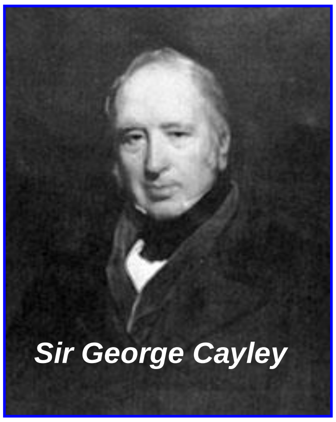

The 3-point system

3. Four, five and six point systems – rarely found in road cars other than very high performance models. The four-point belt has two shoulder straps worn like braces. Ease of movement within the vehicle is less important than being securely fastened in the seat. A five-point system has an extra strap between the legs to prevent the “submarining” effect whilst six-point systems have a strap around each leg. For racing and rally drivers, it is really a matter of choice which gives greater security and control of the vehicle in extreme driving situations not experienced by the normal car owner.

Seat belts are not just heavy duty webbing straps, they are scientifically designed and carefully manufactured to provide durability, the necessary strength to restrain the occupant, and a permissible degree of stretch which helps cushion the impact forces and minimise belt inflicted injury or bruising. The modern automatic latching buckle must be fool-proof and easy to use as well as being able to withstand immense force. Most cars now feature audible and visual warnings which encourage the seat occupant to secure their seat belt if only to stop the bleeping noise! Automatic inertia reel belts are now the norm: a spring tensioned spool allows the belt to extend or retract automatically to accommodate occupants of varying size or bulk, as well as when they change position. A hanging pendulum, incorporated in the spool mechanism, swings in response to any dramatic change in speed or direction and locks the spool to restrain the occupant. Pre-tensioners, fitted to an increasing number of cars, employ sensors located at the extremities of the vehicle to activate small explosive charges within the belt mechanism to pull the occupant back into the relative safety of the seat.

Origins of the seat belt

So, who first thought up the idea? The first accepted application of a seat belt (or seat restraint) is attributed to an 18th century English engineer Sir George Cayley (1773–1857), often called the "Father of Aviation". Indeed, had he had the fortune to be born a hundred years later in the fledgling years of the internal combustion engine, he would unquestionably have been famous in many other fields. Amongst other engineering projects, Cayley designed and built gliders in which he and his employees made a number of flights, some more successful than others. Falling out of a glider whilst in flight was more than likely to be a less than exhilarating once only experience! Landings too were a very uncertain event in which our intrepid aviators had little choice as to the precise spot. Plunging headlong into the unknown involved a risk of being thrown helplessly from the craft. Cayley recognised that his best chances of survival lay in staying secure within the airframe even while it disintegrated around him, so he used belts to secure himself to the seat of his craft. Since Sir George lived to tell the tale and died of old age it is safe to assume his ideas worked.

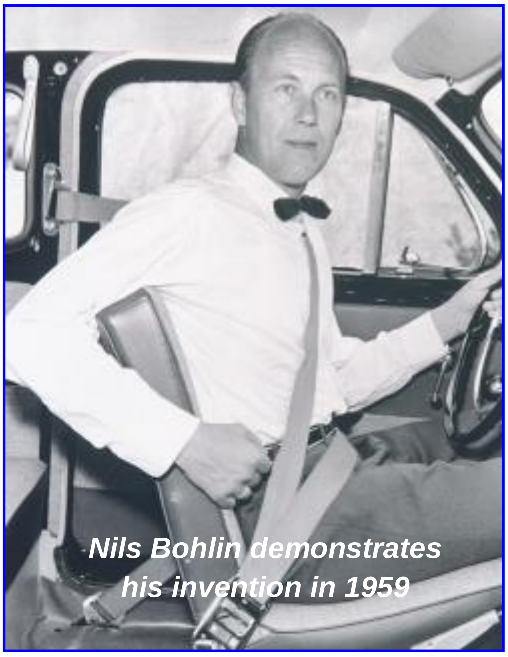


Sir George Cayley

Move forward now to the end of the19th century and the dawn of the motorcar as we know it. In 1885 an American, Edward J Claghorn, patented a safety belt "designed to be applied to the person, and provided with hooks and other attachments for securing the person to a fixed object". Although Claghorn's safety belt was not designed with the car in mind, its possible application was soon obvious. With the rising number of motorists, there were increasing accidents and, particularly in America, a number of physicians became concerned with the nature and cause of motoring related injuries. During the 1930s, a number of prominent physicians fitted seat belts to their own vehicles and began a campaign urging motor manufacturers to fit belts in new cars.

First out of the starting blocks was the American car manufacturer Nash who offered lap belts as an option from 1949. In 1956, Ford and Chrysler offered optional lap belts in the front and Ford's advertising campaign focused heavily on seat belts. That same year the Swedish manufacturer Volvo offered the two-point diagonal chest belt as an option. Motor manufacturers were now increasingly aware that in-car safety was becoming an important selling point for new models. Previous reluctance to fit seat belts, largely because of cost, was replaced by a desire to attract the emerging body of safety conscious motorists. Indeed, around this time a number of manufacturers began to include seat belt anchorage points in their newer models. The 1958 New York International Auto Show saw the introduction of the Saab GT750; for the first time front seat belts were fitted as standard. The stage was now set for other manufacturers to follow suit.

In 1959 Volvo introduced a three point lap and diagonal belt as a standard fitment on all cars sold in Sweden. This belt was destined to become an industry standard familiar to every motorist today. It was designed by Nils Bohlin, a design engineer with Volvo, who had formerly been employed by Saab's aeroplane division working on ejector seats. His three-point lap and diagonal belt was not an original idea, being based on an earlier design patented in 1955 by the Americans Roger W Griswold and Hugh DeHaven. Their design required two hands to secure the belt and left the buckle near to the middle. Bohlin recognised that the average motorist was essentially idle and would not bother with anything complicated that was not quick and easy to use. The brilliance of his design was that only one hand movement was required to position the belt across both chest and hips and secure it to a fixed anchorage point; an action that is now familiar and second nature to us all. It was perfect, it didn't take much time and anybody could do it, so why not use it?



Nils Bohlin demonstrates his invention in 1959

From this time offering seat belts as an option for both front and rear seat became more commonplace amongst all motor manufacturers. Increasingly seat belt anchorage points were fitted as standard allowing any motorists who wished to do so to buy and fit belts as an aftermarket accessory. In 1965, it became compulsory to fit front seat belts to cars built in mainland Europe. The UK followed in 1967 and the 1970's saw the "Clunk Click" advertising campaign promoting their use. Increasing awareness of the danger posed by and to unsecured rear seat passengers encouraged forward thinking manufacturers to provide anchorage points for rear seats too. Unsecured in the back seat, in a head on collision at 30 mph, even your frail old grandma became a potential killer.

Legislation

Legislation governing both the fitting and wearing of seat belts is varied across the globe;

individual countries and states setting their own rules. Despite strong campaigning by safety groups and medical evidence as to their value, legislation regarding seat belts was a long time in coming. Honours go to the State of Victoria, Australia for being the first to pass a law making wearing a seat belt compulsory. Although there were no specific laws in the USA, by 1964 more than half of the states required belts to be fitted in the front but not until 1984 did it become a requirement to use them. In Europe, Belgium and France led the way (1973), making the wearing of seat belts compulsory but only in certain circumstances. In the UK it was not until 1983 that the driver and front seat passenger were legally required to use belts; eventually (1991), this was extended to include rear seat passengers as well.

Although not the inventor of the seat belt, or the first to fit them either as an option or standard, Volvo, to their credit, have not sought to prevent any manufacturer from copying their design. In fact, just about every manufacturer has. Anyone who has had the misfortune to be involved in a serious collision while wearing a seat belt and been fortunate to escape without serious injury, should offer up a word of thanks to Volvo and Nils Bohlin in particular, as well as those earlier pioneers of seat belt design. According to independent research, the chances are more than 60% that it was the seat belt that saved you.

Conclusion

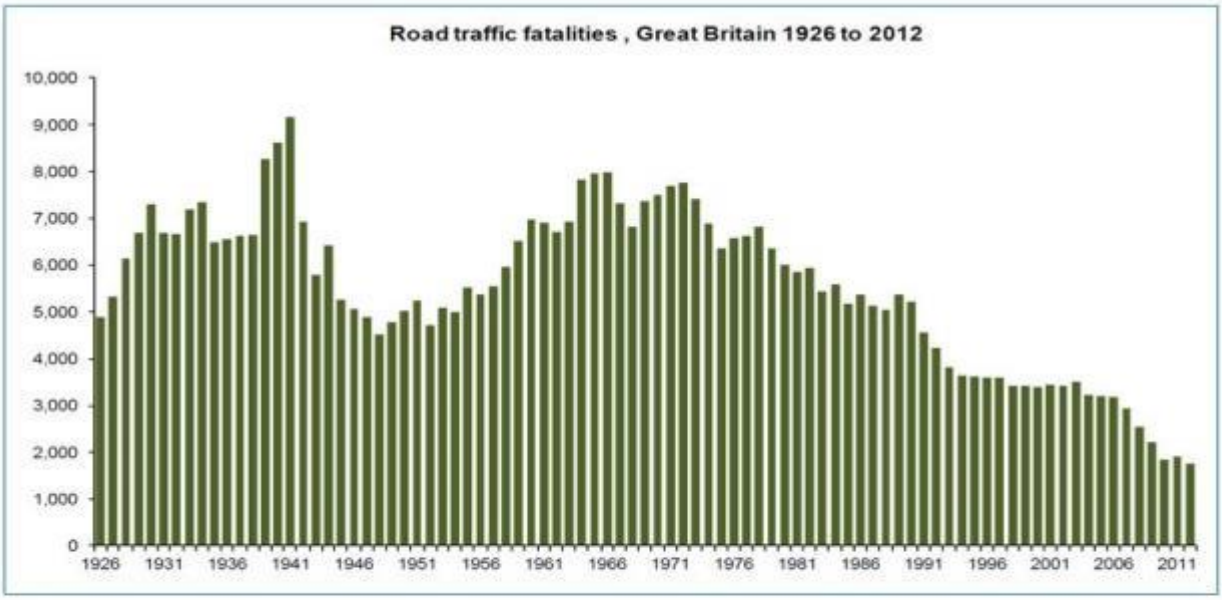
So, what is the future of the seat belt? Clearly, it is here to stay but measures to increase the comfort and effectiveness of the seat belt continue. In a development by Ford, a small airbag has been introduced in the diagonal section of the belt. When the car is involved in a collision, sensors determine the severity of the crash and initiate a rapid flow of gas into the belt. In comparison with a conventional belt, this spreads the crash forces over five times the area of the body, lessening the risk of injury to the occupant.

Maybe the most effective and lowest cost way to improve occupant safety is through encouraging the existing seat belts to be used. Front seat belt usage in the USA in 2010 is reported at 85%: a steady year on year increase. Corresponding figures for the UK show front seat belt usage as 95% and 88% for rear seat passengers. However, a significant minority (28%) of all drivers aged 18 or over do not *always* wear a seat belt. Encouraging all occupants to wear a seat belt is estimated to have the potential to save around 300 lives in a year.

Inevitably, there will always be those opposed to wearing seat belts of any description citing various arguments for not wearing them. Such arguments are invariably flawed or so improbable as to be unrepresentative. We have all heard tales of someone who would have died if they had been wearing a seat belt. Even if true they are a minority; accident research shows overwhelming evidence that wearing seat belts saves lives. Tell them to belt up!

Annex: Fatal accident trends

Whilst it is not possible to separate the effect of seat belts on the safety of vehicle occupants from other advances in vehicle safety design and road improvements over the last 80 plus years, the chart below shows the number of fatalities on the roads of Great Britain over that period. Clearly, since the early 1970s, when there were just under 10 million cars on the roads of Great Britain, the trend has been in the right direction, with a low of 1,754 deaths (801 being car occupants) in 2012: a year when there were 27.28 million cars on the road and falling still further to 1,713 in 2013.



Reinforcing the statistics, subjectively, drivers feel safer in their cars than at any time in the past. The 2012 RAC Report on Motoring found that technology of all forms has increased the feeling of safety that drivers experience in their cars. It states:

> *"Two thirds of drivers aged 70 and over also take comfort from this* [in-car safety features], *against just 43% of drivers aged 17-24, who perhaps never experienced driving cars without many of the safety and hi-tech features that we take for granted today"*.

Picture Captions and Credits

Page 50: Save yourself poster at
http://www.safetycamera.org/Content/filemanager/upload/file/Save_Yourself_seatbelt_poster.jpg
Page 50: 1959 advertising poster
http://www.dailymail.co.uk/motoring/article-1206112/Clunk-click-trip-The-modest-seatbelt-celebrates-50-years-lifesaving-today.html and
http://www.independent.co.uk/life-style/motoring/features/the-man-who-saved-a-million-lives-nils-bohlin--inventor-of-the-seatbelt-1773844.html
Page 51: The three-point system: http://www.securon.co.uk/seat_belt_harness_road_vehicles.htm
Page 52: Sir George Cayley
http://www.flyingmachines.org/cayl.html
Page 53: Nils Bohlin demonstrating the 3-point seat belt.
http://www.wired.com/science/discoveries/news/2008/07/dayintech_0710 and
http://www.automotivetestingtechnologyinternational.com/news.php?NewsID=15216

Construction

Car body design has evolved over the last century in response to many pressures. Some have been social and legislative pressures, some a consequence of improving passenger protection from the elements, some aesthetic, some related to longevity, some to cost of assembly and some to improving safety. Whilst everyone will have a view on the aesthetic qualities (or otherwise) of the four cars shown here (classic, quality or mildly eccentric?), this short chapter concentrates on the pressure to improve safety and its effect on car body design.

The majority of cars manufactured in the period up to World War II were built on a separate chassis. This provided the structural strength and the body was not, generally, a structural part of the car. Although a few specialist companies, such as the Morgan Motor Company, continue to use a separate chassis with a wooden framed, aluminium-skinned body, the last UK mass-produced range of cars to use a separate chassis was the Triumph Herald based range: namely, Herald, GT6, Vitesse and Spitfire. The last Spitfire was produced in August 1980.

The alternative to the chassis-based design was the monocoque or unitary construction. The first mass produced British car to use a monocoque was the 1937 Vauxhall H-Type. In the post-war years, this became the L-Type Wyvern and Velox.

Claims for the new construction included "…greater strength with less weight and freedom from squeaks and rattles …". Other manufacturers quickly followed in adopting this type of construction. Morris and Hillman in the pre-war years were joined by Standard (the 1949 Triumph Mayflower), Austin (1951 A30), Jaguar (1955 Mk1) and others whilst the 1956 Jaguar XK140 in the Cotswold Motoring Museum collection still has a steel and aluminium body on a separate chassis.

In a monocoque construction the car floor pan, reinforced with box-section sills, a transmission tunnel and wheel arches, forms a base for passenger, engine and luggage compartments to be welded in place. These structures share the torsional loads experienced by the body when the car is in motion and are the basis of Vauxhall's claim to reduce "squeaks and rattles". Loss of the separate chassis allowed a lower floor pan, lower seating position and lower roofline so the outward appearance of the mass produced car also changed with the adoption of the monocoque construction. Costs for tooling for the new construction method were high and this may explain its relatively slow adoption and the fact that large volume production was required to offset the initial tooling costs.

The monocoque construction was not all good news for manufacturers. Closed box sections for sills, the inaccessible cavities created between inner and outer wheel arches, front suspension housings and blocked drain holes in sills and doors all contributed to unseen corrosion and 'body rot' on some monocoque designs. Apart from cosmetic problems, more serious structural weakness would usually accompany such corrosion with serious safety implications if the car was involved in a collision. Increased use of galvanised steel, cavity treatment with a wax coating and non-ferrous body sections have all but rendered this problem obsolete on cars over the last couple of decades.

Materials

From the everyday family saloon car to the land speed record challenging Bloodhound via Formula One racing, today, computer modelling and simulation play a major role in car body design. Aerodynamic performance of the body, a key parameter in overall fuel consumption and CO_2 emissions, aerodynamic down force and structural strength in a collision are all modelled in software before a single metal or carbon fibre panel is formed. Modelling allows the selection of steel, aluminium or composite materials to be made to provide an optimum balance between strength and lightweight construction.

A one-piece carbon fibre monocoque body on the new Alpha Romeo 4C provides a lightweight body that is lighter than steel, corrosion resistant and structurally stable and its aluminium monocoque construction looks like being a selling feature on the next generation small Jaguar, the XE model due for launch in 2015. Meanwhile the BMW electric vehicle range is also adopting extensive use of a carbon fibre monocoque.

Safety Testing

Euro NCAP (New Car Assessment Programme) testing was launched in 1997 with the objective of reducing the injury to car occupants and pedestrians in the event of an accident. Members of the independent organisation include government transport departments plus consumer and motoring organisations throughout Europe. The current rating system for car safety considers the performance of the car in protecting the safety of adult and child occupants, pedestrians and the potential of advanced driver assistance technologies such as stability control. An overall rating of up to five stars is awarded and below the star rating, further percentage ratings are awarded in each of the above four categories. Finer detail is published in each category, for example, adult safety comprises a points score for driver and passenger frontal and side impact and whiplash. A typical assessment report for a Skoda Octavia is shown in the link.

It is important to recognise that ratings are awarded to a range of vehicle classes from "Supermini" to "Large Off-Road 4x4" (eleven classes in all). Within each class, cars that are within 150kg of each other are considered to be comparable. It would be a mistake to assume that a 2013, five-star rating for a Supermini and a large off-road car would afford the same protection to both sets of occupants should the vehicles collide with each other or with an immovable object. In general, the occupants of the larger, higher vehicle fare better than those in the smaller vehicle.

In spite of resistance from some motor manufacturers in the early days of crash testing, there is no doubt that the improvements in safety achieved by those same manufacturers in response to the Euro NCAP initiative is reflected in the increasing number of five star awards in all vehicle classes whilst, simultaneously, the performance to achieve the top rating has become stricter over the years.

Picture Captions and Credits

Page 56: Cadillac rear light cluster, Vauxhall PA Cresta, 3½ litre Bentley and E-Type Jaguar from 2013 and 2014 Classic Motor Show at the NEC, Birmingham
Page 56: Assembly underway in the Morgan factory, 2014
Page 56: Rolling chassis of a 1972 Triumph Spitfire – origin unknown
Page 57: Jaguar XK140 at the Cotswold Motoring Museum
Page 57: Inner and outer sill corrosion above a jacking point - origin unknown
Page 58: Euro NCAP logo http://www.euroncap.com/files/Euro-NCAP-Guidelines-2011---0-a4da2bfa-3d4f-4ec5-8429-7a0bf665b89d.pdf

How did the "Catseye" come to be invented?

Safety of a driver depends not only on the properties of the car being driven but also on the quality and design of the road infrastructure. This chapter on the "Catseye", or more correctly, the reflective road stud, sets out to describe the background to this invention, the principle on which it operates and how the technology is moving on.

Introduction

"Catseyes" were invented and patented in 1934 by Percy Shaw (1890 - 1976) from Halifax in Yorkshire. Specific events that prompted the invention have been widely reported. They include his observation of his car head lights being reflected from the eyes of a cat by the side of the road, thus avoiding him driving off of the road, and the use of reflections from tram lines to provide guidance and the problem encountered when the tram lines were removed. Perhaps it was both of these events that sparked the invention but one theme common to both tales is that the observations were made whilst travelling home, downhill from the Old Dolphin pub in Queensbury one misty night.

Depressing the rubber insert wipes the front of the reflectors

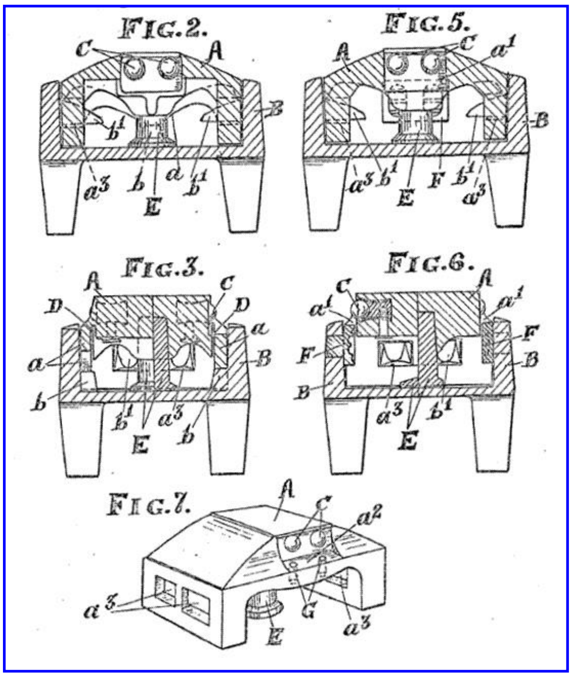
The company, Reflecting Road Studs Ltd, was founded by Shaw in 1935 to produce the item that we still use today and "Catseye", although widely used as a generic description, is a registered trademark of that company: hence the quotation marks. Their website also provides a good background to the "Catseye" road stud product.

The twin reflectors are mounted on each face of a black or white rubber insert: the reflector colour being selected depending upon the location of the stud (see Annex to this chapter). Depression of the insert by passing traffic causes the outer surface of the reflectors to be wiped against the rubber thus helping to keep them clean. The third component of the "Catseye" is the cast iron base. This has to be sufficiently robust to withstand heavy traffic and occasional snow ploughing. The rubber inserts can be exchanged without having to remove the cast base from the carriageway.

Patents

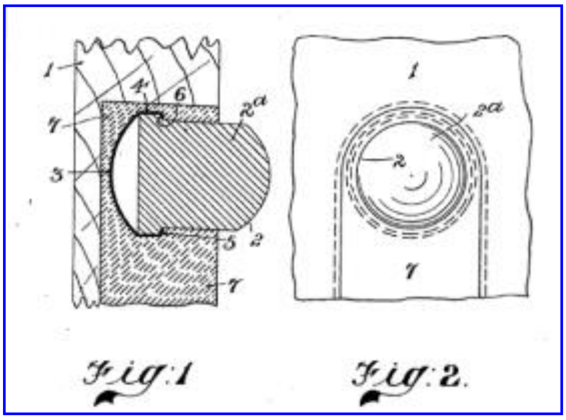
Shaw applied for and was granted two patents in respect of the "Catseye". The first application (Patent GB 436290) was made on 3 April 1934 and concerned the concept of "Blocks for Road Surface Markings"; specifically the displacement of the block when driven over by a vehicle and the embedding of reflectors in the walls of the blocks.

The second application (Patent GB 457536) was made on 31 May 1935 and addressed the self-cleaning of the reflectors by both the squeegee effect of wiping the reflector surface on a lip in the rubber mount and by air or water flow (if the road was wet) over the reflector as the block was depressed. What is apparent in reading both patents is the extent to which they focus on the mechanical design of the "Catseye". The reflectors receive very little mention and the optical principles of their design are not mentioned at all.



There are however, other claimants to the invention of one critical component of the reflective road stud. In particular, Richard Hollins Murray, at one time resident at Dinmore Manor, Herefordshire, patented the use of reflecting lenses for reflective markers or advertising signs. Patent GB 289619, applied for in 1927, addressed techniques for assembling light-reflecting devices to form "indicators, advertising signs or the like". It references two earlier patents of Richard Hollins Murray, namely patent GB 256475, applied for in 1926, which focused on assembly of a two-part light reflecting device and techniques for its fabrication.

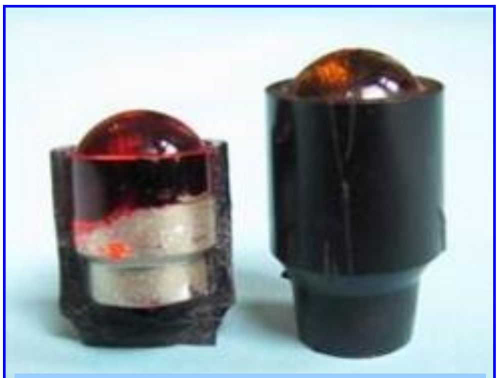
His earlier patent, GB194034, applied for in 1921 and completed in 1923, concerned the design of the optical reflecting device itself. Although still including the aspects of how to mount the device for practical usage, this patent also addresses the optical properties of the plano-convex lens (the convex surface being the front of the device – item 2 in the diagram right) and the separate concave reflector (item 3) mounted behind the plane surface of the lens.



Diagrams from Patent GB194034

The use of reflectors in kerb stones or on roadside markers was also the subject of a patent application by Fredrick Lee in 1932. In his application, which was not funded to completion, the reflector is described as "a bi-convex crystal lens combined with a burnished reflector" or a "plurality of prismatic-like elements". (See panel at the end of this chapter). The image below is taken from the Fredrick Lee website link and shows prototypes of his reflective studs in three different

colours. The image to the right is of two studs extracted from a modern "Catseye" with part of the protective surround removed from one stud. In addition to the similarity between these images of hardware produced eighty years apart, the folded, crimped metal attachment between lens and reflector in the Fredrick Lee patent application is remarkably similar to the diagram and "embodiment of the invention" specified by Richard Hollins Murray in his 1926 patent; GB 256475.



Reflective studs from amber and red "Catseyes". The surround of the red stud has been cut away to reveal the silvered backing to the concave mirror. The convex lens and concave mirror are formed from a single piece of glass.

With many inventions it is often the case that, rather than a single flash of inspiration, the invention is an iterative process, building on earlier ideas and proven concepts but applying them to a fresh set of circumstances or implementing them in a specific fashion. The history of the reflecting road stud appears to have followed this path. What is beyond doubt is that Shaw built on the known optical properties of reflecting lenses, mounted these in a robust, practical housing and established facilities to cost-effectively mass produce the "Catseye". He is the person to whom thanks are due for an item that has made driving in poor visibility much safer than it was during those misty nights, descending the hill from the Old Dolphin pub in Queensbury, in 1934. Further images of Percy Shaw, "Catseyes" and their installation are contained in a Design Museum reference.

The alternatives

What has changed in the design and implementation of reflective roadstuds since Percy Shaw started manufacturing the "Catseye" in 1934? With the exception of the solar powered, LED roadstuds shown later, the basic principles of operation have not changed. Lighter supports than Shaw's cast iron base are used for the reflective surfaces and their mounting. Epoxy adhesives as well as the more traditional bitumous-based adhesives are used to fix the studs to the carriageway and some of the low profile designs avoid the need to form a recess for the stud in the carriageway. Some manufacturers replace the clear or coloured glass reflectors of Shaw's "Catseyes" with protected, plastic prismatic reflectors (See panel at end of this chapter).

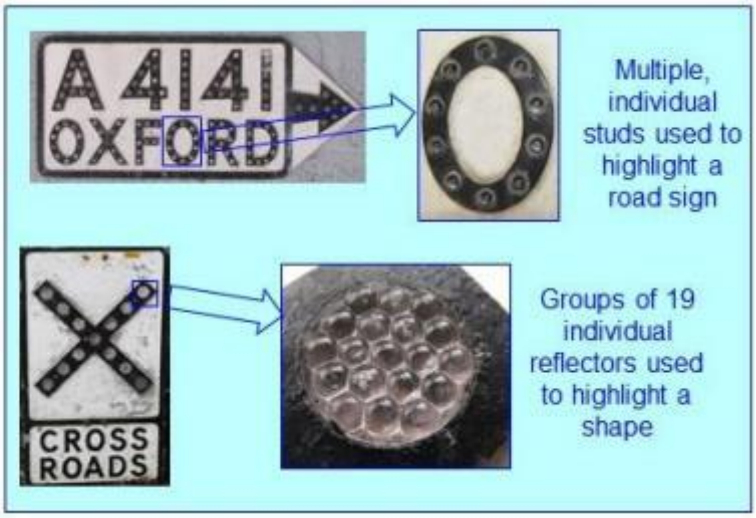
Still based on the "Catseye" principle but now providing reflection of incident light over 360-degrees, is the Holophane roadstud: shown to the right. These, unlike the "Catseye", have no moving parts. They are sunk into a circular recess in the carriageway or pavement edge and are of sufficiently robust glass construction to withstand the abrasion and impact of a roadside environment. In particular, the reflective surface is below the road surface and therefore unlikely to suffer abrasion.

Relatively recent additions to the range of studs available are those based on the use of a battery-powered Light Emitting Diode (LED) with the battery recharging via a solar cell or inductive power transfer. The solar powered example on the left below is embedded in a bored recess in the carriageway with just 4mm protruding and claims to improve visibility range by a factor of 10 over a reflective stud. The stud on the right is designed to be surface mounted on the carriageway. Similar, solar powered rechargeable studs are available to the consumer market for emergency hazard beacons in the event of a roadside breakdown.

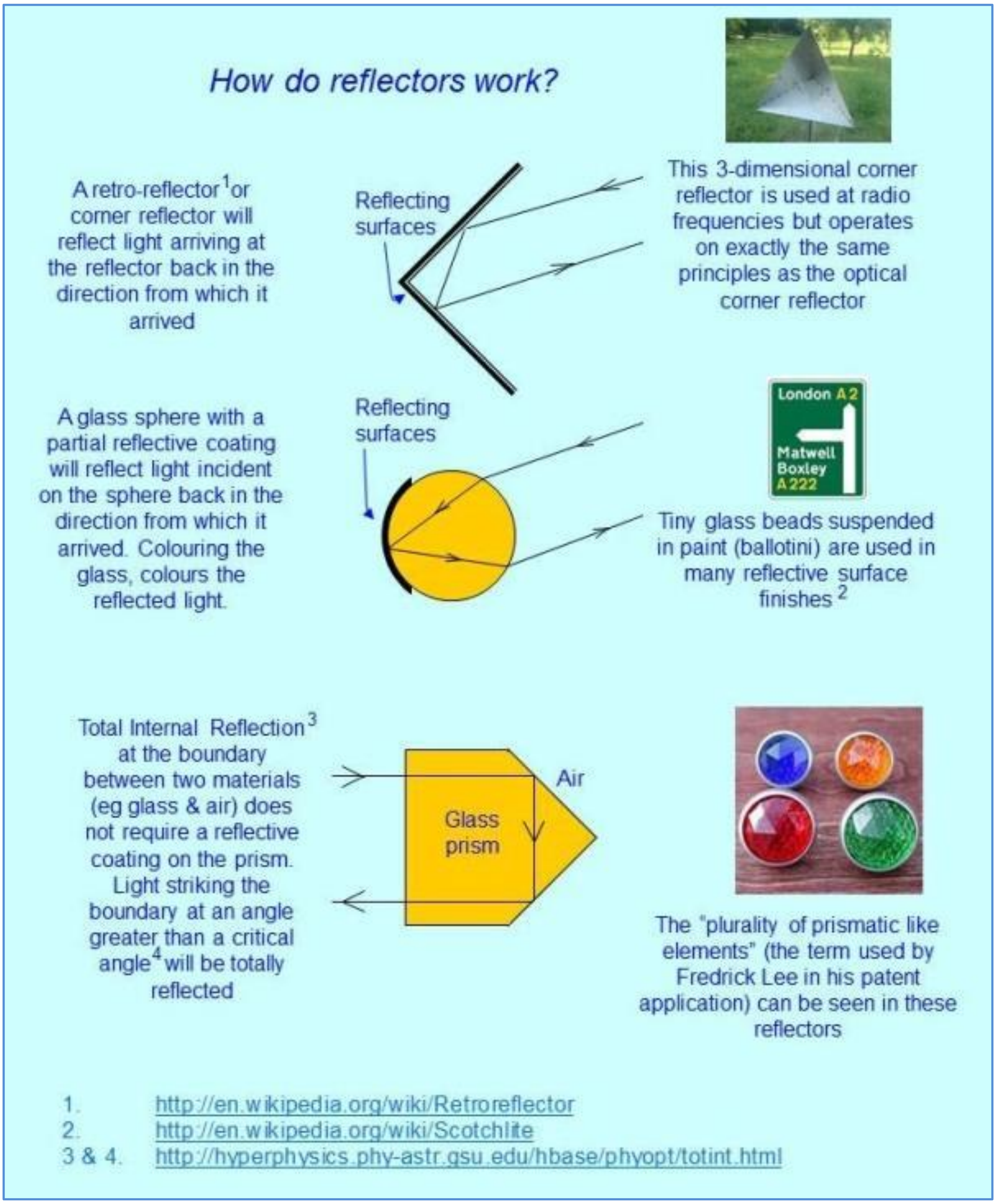
Powering the LEDs through inductive power transfer has been considered for over 15 years but only relatively recently have studs based on this concept been deployed.

Spin-off

The aforementioned Richard Hollins Murray and Fredrick Lee both proposed the use of reflectors mounted vertically by the roadside to act as a warning of crossroads, bends and



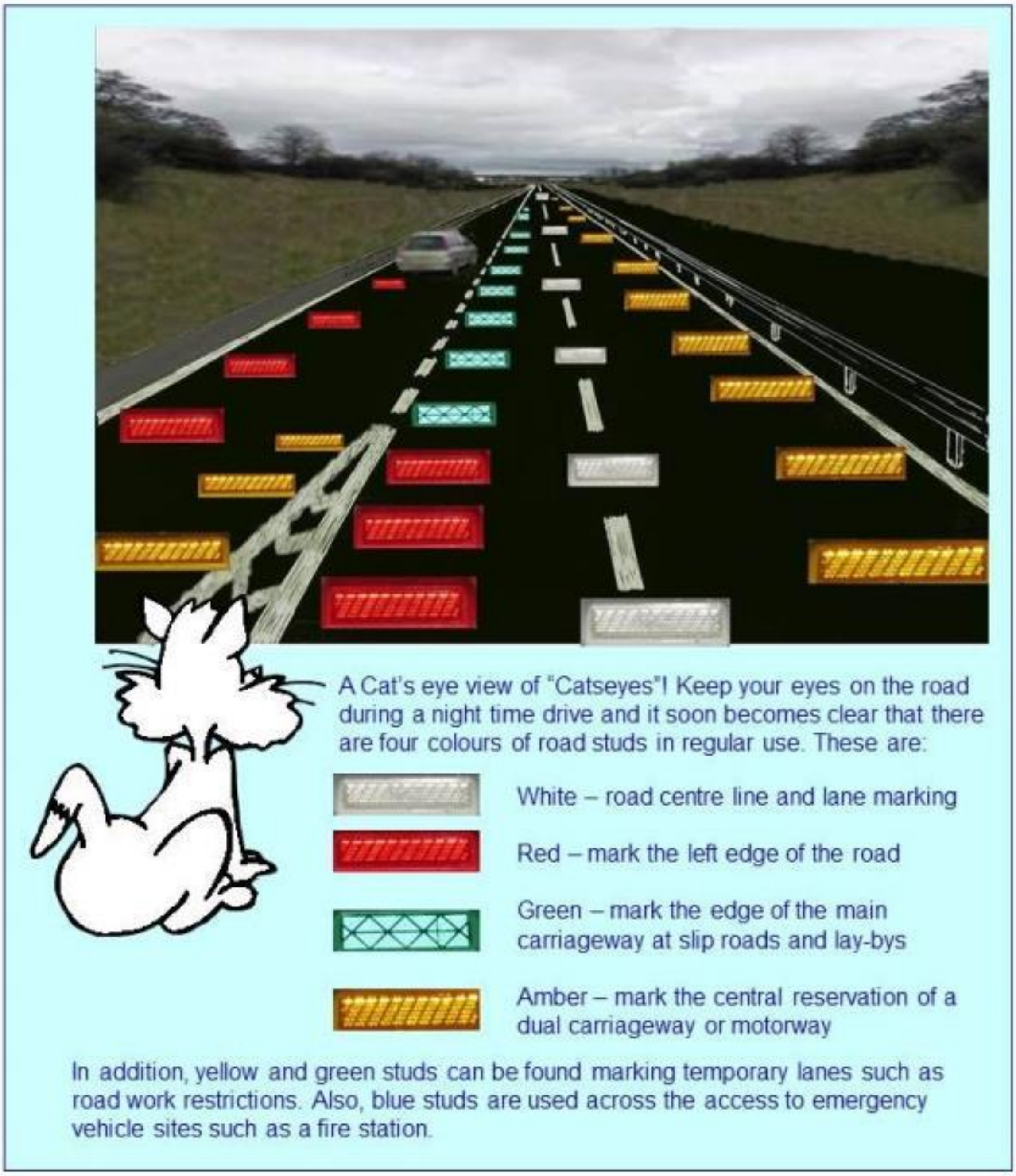
other hazards. In addition, Fredrick Lee suggested that reflectors on the outside of a bend should be of a different colour to those on the inside of a bend; a feature still used today on unlit, rural roads.



Conclusion

Percy Shaw OBE would no doubt be amazed at just how long his invention has survived, virtually unchanged, and also how others have built on his ideas and exploited 21st century technology to provide carriageway illumination and hence enhanced driver safety. It is recorded that Percy Shaw did not move from his house in West Yorkshire and did not let the fortune, amassed through retaining all rights to his invention and keeping manufacture within his own company, change his life style. Apparently, his only extravagance was to keep his basement well stocked with a favourite beer for his frequent parties. Whether the Old Dolphin pub in Queensbury suffered a fall in business as a result is not recorded!

Annex: Coloured “Catseyes”



Picture Captions and Credits

Page 59: The genuine Percy Shaw “Catseye”
Page 60: Cross-section of the “Catseye”
Page 60: Reflective sign at the Cotswold Motoring Museum & Toy Collection
Page 61: The Fredrick Lee studs sourced from the website (http://www.catseyes.com/)
Page 62: An assortment of reflective roadstuds from “A History of Motoring in 10 Objects” exhibition
Page 63: A pair of LED roadstuds from “A History of Motoring in 10 Objects” exhibition
Page 63: Detail of road signs at the Cotswold Motoring Museum & Toy Collection
Page 64: Prismatic reflector from Google images

The Cotswold Motoring Museum and Toy Collection is not just about cars. Toys that our parents and grandparents played with as children, everyday artefacts from the Victorian and Edwardian era plus an insight into the social history of the village of Bourton-on-the-Water and much more can be found in the Old Mill, alongside the River Windrush.