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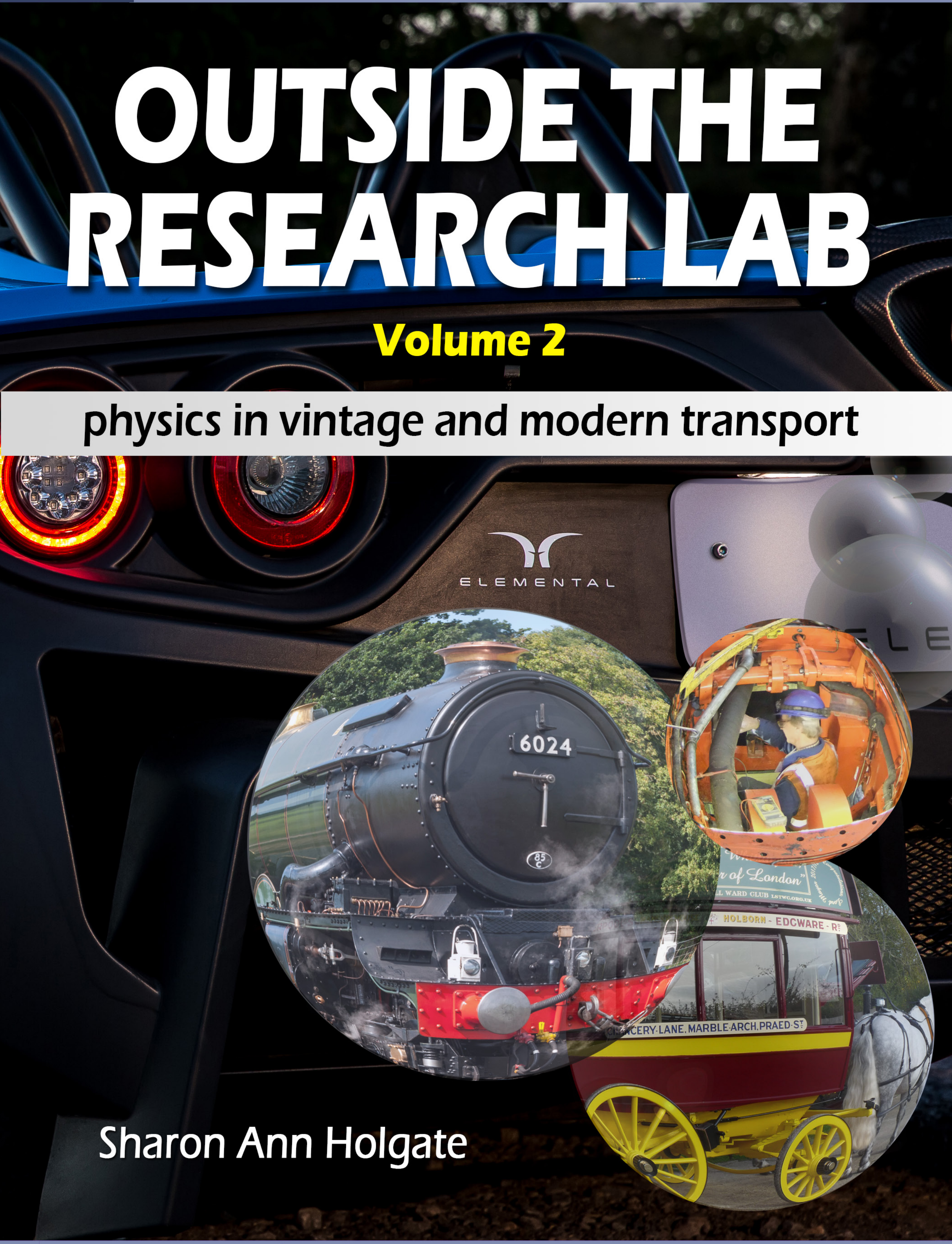
OUTSIDE THE RESEARCH LAB

Volume 2

physics in vintage and modern transport



Sharon Ann Holgate

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Outside the Research Lab

Volume 2: Physics in vintage and modern transport

Outside the Research Lab

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Science writer and broadcaster, doctor of physics

Morgan & Claypool Publishers

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For my mother Joan

Contents

Preface

Several of my favourite childhood memories involve aircraft, locomotives, or vehicles. My earliest is of a fast jet from the RAF's Red Arrows display team buzzing the seafront which I was walking along with my Mum. I can recall the lady next to us emitting a terrified scream, while I asked my Mum to lift me up onto a low wall so I could get a better view as the plane made a second pass. I can remember being absolutely transfixed and reaching up towards the jet as if I could touch it. Perhaps not surprisingly, 'fighter pilot' featured on my list of potential career options to explore as a teenager.

Sports cars offered an equal fascination, fuelled no doubt by being taken for a spin in a Lamborghini Countach when I was 8 years old, and being driven round the Goodwood Historic Motor circuit in a beautiful Jaguar E-type which had taken part in Le Mans back in the 1960s.

Likewise steam locomotives were a firm favourite as I was growing up, with many a trip to a preserved railway in school holidays, and hours spent poring over books about locomotives and the UK rail companies in the days of steam. However, my standout memory from that time has to be a footplate ride on one of the most famous steam engines in the world—the A3 Pacific class locomotive *Flying Scotsman*. I can still clearly recall the tremendous heat when the fireman had to open the firebox door to add more coal, and trying desperately to bend my knees so I didn't need to cling onto the handrail and so look like the novice I in fact was.

Perhaps not surprisingly, I still have a fascination for all these types of transport. This led me to come up with the idea for this book which explores some of the physics and technology inherent to preserving and restoring old forms of transport, and creating modern transport for today, and for our future needs. I am hoping that this book—as with the others in my *Outside the Research Lab* series—will provide students and other readers with an interesting insight into some of the diverse applications for physics outside of research laboratories. To help achieve this goal, I have chosen to cover several different aspects of transport, ranging from the restoration of vintage buses to the materials used in the latest supercars. In each case I have interviewed experts working in that field, who have generously given their time to explain how physics and technology impact on their work, and also provided some stunning images.

To keep the book accessible for readers with a wide range of backgrounds, I have only included a small number of equations, and have explained the less familiar scientific terminology and notation. In addition, the more detailed physics is presented in boxes that are interspersed among, but separate from, the main text.

I make no apology for choosing to write about topics that I have a personal interest in—and in some cases have previously written articles about—as I suspect I won't be alone in my enthusiasm for these subjects! I hope they will not only provide an interesting general read, but also some useful examples of how the physics encountered in taught courses relates to the real world. As someone who has written extensively about careers, I also hope the contents of this book might inspire readers as yet undecided on their future career, or looking for a change in direction, to think about career options that they might not otherwise have considered.

Acknowledgements

As with the first volume in this series, I could not have written this book without the help of many people. I would first like to thank my editor Nicki Dennis for approaching me to write for the IOP Concise Physics series, and for her help throughout the creation of this volume. Thanks are also due to Brent Beckley, Karen Donnison, Ana San and Mitra Sayadi at Morgan & Claypool, and Chris Benson at Institute of Physics Publishing.

In addition, I'd like to extend my gratitude to all the interviewees who have kindly given their time, expertise and advice, and allowed me to reproduce some fantastic images. I could not have written this book without your enthusiasm and support. I would also like to thank the various experts, press officers, marketing professionals, and enthusiasts who helped me to secure interviews and kindly provided me with additional information and images. These include Mark Allatt from the A1 Steam Locomotive Trust, John Begley from the Elemental Motor Company, Brian Humber and Charlie Ralph at the Spa Valley Railway, Bernhard Lott, Evelyn Necker and Kerstin Schirmer from Siemens, Tony Sparkes, John Stiles, and Ian Tonkin at Continuum Communication. Thanks are also due to Julian Mayers, Ian Rennison and Tracey deWhalley for their help in various ways with this project.

As ever friends and family members have been a tremendous support, in particular Dawson Chance, Larry Crockett, David Culpeck, Rob Scovell, Emma Winder, and my mother Joan.

About the author

Sharon Ann Holgate

© Sharon Ann Holgate. Photo by Stuart Robinson.

Sharon Ann Holgate has a doctorate in experimental physics from the University of Sussex in the UK, where she was a Visiting Fellow in Physics and Astronomy for nine years, and is a Chartered Scientist and Chartered Physicist. She has worked for twenty years as a freelance science writer and broadcaster, with broadcast credits including presenting on the BBC World Service and BBC Radio 4, presenting video podcasts for medical research charity the Myrovlytis Trust and appearing on a 'Boffins Special' of the *Weakest Link*. Her articles have appeared in *Science*, *Science Careers*, *New Scientist*, *The Times Higher Education Supplement*, *E&T*, *Flipside*, *Focus*, *Physics World*, *Interactions*, *Materials World*, *Modern Astronomer*, and *Astronomy Now*, while her first book *The Way Science Works* (a children's popular science book co-authored with Robin Kerrod) was shortlisted for the Aventis Prizes for Science Books Junior Prize. She was a contributor to the popular science books 30-*Second Quantum Theory* and 30-*Second Energy*, and her undergraduate textbook *Understanding Solid State Physics* is currently in use as a core text in universities around the world. Her first book for this IOP Concise Physics series was *Outside the Research Lab Volume 1: Physics in the arts, architecture and design*. She has also written careers material, case studies, and press releases for the Institute of Physics and careers material and brochures for The Institute of Physics and Engineering in Medicine, and given talks at venues including the Science Museum in London. Dr Holgate was the Institute of Physics Young Professional Physicist of the Year for 2006, won a Merit Award in the 1994 Daily Telegraph Young Science Writer of the Year competition, and was shortlisted for the radio programme category of the Association of British Science Writers' Awards in 2005. Outside of work she collects contemporary ceramics, is a regular visitor to art galleries and museums, and enjoys learning about fashion history and steam locomotives. Further information may be seen at www.sharonannholgate.com.

IOP Concise Physics

Outside the Research Lab

Volume 2: Physics in vintage and modern transport

Sharon Ann Holgate

Chapter 1

Introduction

When you hear about the latest physics breakthroughs on the news, or attend university or college physics courses, it can be easy to think of physics as nothing other than an academic subject. But physics does much more than just describe how matter and energy behave, and so reveals how almost everything around us, and even within us, works. In fact physics-based technologies are integral to many of the work and leisure activities we carry out every day without giving science a second thought.

In this book we will explore the use of physics in vintage and modern transport. We will see how professionals and enthusiasts in different transport-related fields use physics, and physics-based technologies, to design, build, and restore vehicles and locomotives, and enable them to be operated safely.

For instance, we will see in chapter 2 that in order to haul special excursions on the mainline, steam locomotives require complex electrical systems which include on-board electronic safety equipment and railway-standard lighting (see figures 1.1 and 1.2), while the electrical systems of vintage diesel engines need careful maintenance to keep them on track at preserved railways.

Chapter 3 reveals how developments in materials and methods of processing, along with CAD packages, finite element analysis, and computational fluid dynamics are enabling the creation of supercars with outstanding levels of performance both on and off the track (see figure 1.3).

In the final chapter, chapter 4, we hear how physics-based technology is used to help restore and maintain horse drawn buses (see figure 1.4). As this section reveals, while these technologies were not available, physics knowledge was integral to the original development of horse buses in the nineteenth century. This chapter also describes the technology being used to restore a vintage Greyhound diesel bus, and what features made it so advanced for its time.

For each chapter, I have spoken with experts working in the respective fields, who have given an insight into their work and how physics impacts on it. Additional

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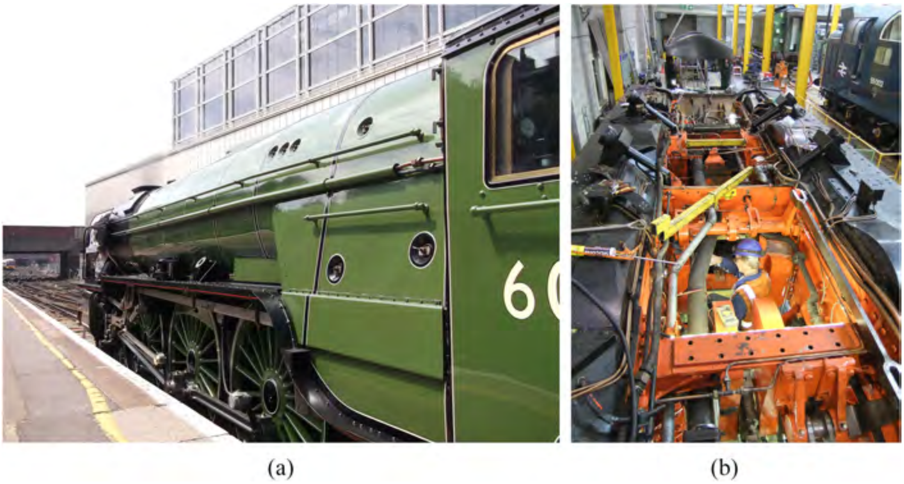

Figure 1.1. New build steam locomotive *Tornado*. (a) The locomotive ready to depart from Victoria station in London on Friday 27 May 2016. (© Sharon Ann Holgate, 2016.) (b) Testing *Tornado's* electronics during a routine overhaul. The electrical system contains over 9000 individual electrical and electronic components. (© Rob Morland, A1SLT. Reproduced with permission.)

Figure 1.2. GWR King class locomotive (number) 6024 *King Edward I* in 1995 exiting the 1000 m long Whiteball Tunnel—which passes under the county border between Somerset and Devon in the UK, was designed by Brunel, and was built in 1844. Electronic safety equipment has been retro-fitted to this 1930s locomotive to enable safe running on the modern mainline. (© Martyn Bane. Reproduced with permission.)

details about the physics mentioned, and related physics topics, are presented in boxes interspersed among the main text.

Throughout this book I have used the SI system of units when describing the sizes of measurable physical quantities—which include mass, length, pressure, electric

(a) (b)

Figure 1.3. The *Elemental Rp1* track day car. (a) The *Rp1* has a carbon fibre tub, side pods, and dash panel, and thermoplastic composite Coats Synergex wheel arch liners. (b) These initial sketches of the *Rp1's* bodywork by Guy Colborne were created after the ideas for the chassis and tub had been worked up in a CAD package. (© Elemental Cars Ltd. Reproduced with permission.)

Figure 1.4. An 1897 horse bus, owned and restored by Tony Drewitt, taking part in the Lord Mayor's Parade in London in 2012. (© John Stiles. Reproduced with permission.)

current, and time. (The only exceptions to this are in instances where vintage or specialist vehicles are being discussed, and alternative units are more appropriate as they are widely used in that context.)

The SI system of units—Système Internationale d'Unités to give it its full title—is, as its name suggests, the internationally agreed system for detailing the sizes of physical quantities. One of its main advantages is removing any confusion that can be created by using different systems of units to describe the size of the same quantity, and hence having to convert numbers from one unit to another. Such as, for instance, converting a temperature measured in Fahrenheit into its SI unit of Celsius. Table 1.1 shows a selection of physical quantities along with their

Table 1.1. Some physical quantities and their respective SI units.

Physical quantity	Name of SI unit	Symbol of SI unit
mass	kilogram	kg
time	second	s
length	metre	m
electric current	ampere	A
electric potential	volt	V
force	newton	N
pressure	pascal	Pa
power	watt	W
frequency	hertz	Hz
energy	joule	J

Table 1.2. Prefixes used to describe multiples of SI units (a) getting smaller, where 10^{-3} is a shorthand way of writing 0.001, and 10^{-6} is equivalent to 0.000 001, and so on. Part (b) shows the prefixes for getting bigger, where 10^2 is equivalent to 10 × 10 i.e. 100, and 10^3 is mathematical shorthand for 10 × 10 × 10 i.e. 1000, and so on.

(a)

Factor	Prefix	Symbol
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a
10^{-21}	zepto	z
10^{-24}	yocto	y

(b)

Factor	Prefix	Symbol
10	deca	da
10^2	hecto	h
10^3	kilo	k
10^6	mega	M
10^9	giga	G
10^{12}	tera	T
10^{15}	peta	P
10^{18}	exa	E
10^{21}	zetta	Z
10^{24}	yotta	Y

associated SI unit, while table 1.2 lists the prefixes used to describe multiples of SI units.

As table 1.2 reveals, some symbols are uppercase, and others are lowercase. It is important not to muddle the two as the same letter can represent very different sized units. For example, lowercase m stands for *milli* while M denotes *mega*. Different countries can vary in how they use SI units. In some countries for instance drinks are labelled in ‘cl’ while in other countries the labels show the quantity in ‘ml’. So a 25 cl bottle of mineral water holds the same volume of liquid as a 250 ml bottle of mineral water.

As Greek letters are used to describe some of the quantities covered in this book, table 1.3 provides a quick reference point for the Greek alphabet.

Each chapter concludes with some suggestions for further reading and a selection of web links—including links to video footage and additional photographs—that will enable the work of the various interviewees, and in some cases the physics topics covered, to be explored further.

Table 1.3. The Greek alphabet.

Capital Letter	Lowercase Letter	Name
Α	α	alpha
Β	β	beta
Γ	γ	gamma
Δ	δ	delta
Ε	ε	epsilon
Ζ	ζ	zeta
Η	η	eta
Θ	θ	theta
Ι	ι	iota
Κ	κ	kappa
Λ	λ	lambda
Μ	μ	mu
Ν	ν	nu
Ξ	ξ	xi
Ο	o	omicron
Π	π	pi
Ρ	ρ	rho
Σ	σ	sigma
Τ	τ	tau
ϒ	υ	upsilon
Φ	φ	phi
Χ	χ	chi
Ψ	ψ	psi
Ω	ω	omega

It is difficult to predict exactly what impact current physics research will have on the transport of the future, and on our ability to keep vintage transport in working order. But if the last 150 years are anything to go by, it seems likely that the influence of physics, and the technologies it helps create, will continue shaping not only the contemporary transport we all use, but also determine the fate of the vintage vehicles and locomotives that we enjoy travelling in or behind in our leisure time.

Chapter 2

Chip off the old block—electrical systems and electronics in steam and historic diesel locomotives

2.1 Introduction

One of the most popular family days out in the UK involves travelling behind a steam locomotive either on the mainline or at a preserved steam railway. Whilst the experience needs to feel like stepping back in time, modern safety requirements must be met, and this involves a surprising amount of electronics.

In this chapter we will first hear from Rob Morland, Director of Electricals for The A1 Steam Locomotive Trust. I first interviewed Rob for an *E&T* feature on *Tornado*'s electricals, which formed the inspiration for this chapter. Here he explains what electronics is carried on board *Tornado*—one of the world's newest steam locomotives—and which features and systems its electrical circuits have to support. In addition Rob's colleague Alan Green, who designed the lighting system for *Tornado*, details the lights used for the locomotive.

Thanks to Martyn Bane, Deputy Engineer with the 6024 Preservation Society Ltd, we will then discover what electronic systems must be retro-fitted to heritage ex-GWR steam locomotive number 6024 *King Edward I* to ensure safe operation on the mainline. At the time of writing this book, Martyn is working on overhauling 6024's electrical system ready for the locomotive to return to mainline operation, which is provisionally scheduled for 2019.

We will then hear about one of my favourite locomotives, the Class 09 diesel electric shunter number 09026. I used to look out for this locomotive whenever I took the train between Brighton and London as it worked in the depot at Brighton station for many years. In 2016 the locomotive went into preservation and was moved to the heritage Spa Valley Railway whose engineers are, as General Manager Jonnie Wesson explains, currently overhauling it. As Jonnie reveals, there is work to be done on the electrical system in order to keep this powerful little workhorse on the rails.

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The chapter concludes with a look at the electrical system on-board the 1948 *Cedar Rapids* Skytop parlour lounge observation car. Thanks to Steve Sandberg, President & Chief Operating Officer of the car's current owners the Railroading Heritage of Midwest America, we will hear why the original electrical system needed replacing before the car could return to the rails.

2.2 On-board a 21st century steam locomotive

In December 2008, registered charity The A1 Steam Locomotive Trust unveiled their Peppercorn class A1 Pacific locomotive *Tornado*, which had taken their volunteer-run workforce nearly 20 years to build.

Tornado (see figures 2.1 and 2.2) was created to plug a gap in British railway history, as none of the 49 original A1s—designed by Arthur Peppercorn for the LNER (London and North Eastern Railway) to haul express passenger trains, but

(a) (b) (c)

Figure 2.1. *Tornado* at Victoria station on Friday 27 May 2016 about to depart with a Belmond British Pullman excursion; (a) front view, (b) inside *Tornado's* cab: the driver's seat is shown on the left-hand side; (c) view showing *Tornado's* tender, which can carry 7.6 tonnes of coal, and approximately 27 276 litres (6000 gallons) of water. This gives the locomotive a range of around 161–177 km (100–110 miles) before needing to take on extra coal and water. (© Sharon Ann Holgate, 2016.)

Figure/Video 2.2. *Tornado* departing Victoria station, London on Friday 27 May 2016. (© Sharon Ann Holgate.) Video available at https://doi.org/10.1088/978-1-64327-270-2.

built through 1948–49 after the formation of British Railways—had been saved for preservation. However *Tornado* is more than a replica. The use of modern alloys and computer aided design has contributed to producing a decidedly 21st century steam locomotive, as has the unique modern electronics system which is integral to its design. This includes LED lighting, a mobile phone charger, a radio communication system, GPS satellite positioning, and electronic safety equipment—all powered by steam.

As Rob Morland, Director of Electricals for The A1 Steam Locomotive Trust, explains, *Tornado's* electrical system is made up from 'over 9000 individual electrical and electronic components and 36 circuits protected by MCBs [miniature circuit breakers]'. These are connected together via three and a half miles of low smoke zero halogen (LS0H) wiring—which meets the latest flammability regulations and is the same as that used on all modern locomotives—sitting inside galvanised steel conduit, and 52 military specification MIL-C-5015 bayonet connectors that can work from −50 °C to +125 °C, making them ideal for use on-board a steam engine. Figure 2.3 shows an overview of the system.

To comply with modern safety regulations, *Tornado* must carry the Train Protection and Warning System (TPWS)—which automatically applies the brakes if the driver is going to pass a red signal—and an On Train Monitoring Recorder (OTMR), says volunteer Rob, who by trade is a communications and electronics consultant. 'OTMR is the railway version of a "black box". It has a set of inputs which are connected to different parts of the locomotive, so it can record things like boiler pressure, steam chest pressure, speed, and applied brake force pressure,' he explains.

The locomotive must also carry a radio that enables footplate crews and signalmen to contact each other. In fact *Tornado* has carried two such radio

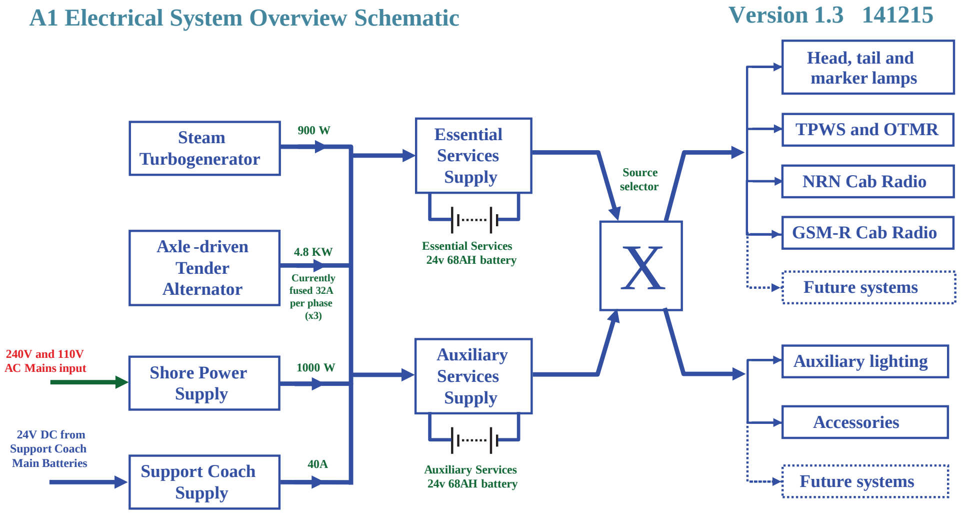


Figure 2.3. Schematic overview of *Tornado's* electrical system. (Courtesy of Rob Morland. © A1 Steam Locomotive Trust 2015. Reproduced with permission.)

systems—the legacy analogue NRN radio (National Radio Network) that is now switched off, and its GSM-R replacement. The latter is a GSM (Global System for Mobile communication) digital communications system which has particular frequencies allocated solely for railway use. GSM-R is part of the European Railway Traffic Management System (ERTMS) that will eventually replace the UK's TPWS. Rob says they already have detailed plans for installing the rest of the ERTMS system on a space available in *Tornado's* tender as soon as Network Rail (who own and operate the rail network infrastructure in England, Wales and Scotland) require them to.

The original 1940s electrical system on the A1 consisted of a small turbo-generator which powered tail lights and marker lights on the engine, as well as cab lighting. 'The A1s had no batteries on board and powered those lights from a 24 V turbo-generator, which was essentially a mini steam turbine connected to a dynamo or an alternator,' says Rob. [See box 2.1 for more on steam turbines.] 'Some heritage [preserved original] engines still have their original turbo-generators which they use for powering their lighting. But for powering the essential services such as the TPWS and OTMR most heritage steam locomotives use lead acid batteries.' These are charged from the AC mains while the engine is in a shed. The charged batteries then provide power during a day of operations. 'These locomotives will run quite happily on batteries for a whole day, but they will then need recharging before another run,' adds Rob.

Rather than using a similar system, the A1 Trust wanted an on-board power supply for *Tornado's* electrical system. 'We've designed a power supply with three different methods of charging. We have a steam-powered turbo generator [see figure 2.5] which provides about 32 A into our power supply, and an axle driven high-current alternator on the tender (driven by belts off a pulley wheel on one of the

Box 2.1. Steam turbines

Whilst steam driven technology might sound old-fashioned, it is actually a cornerstone of modern life. This is because a steam turbine driving an electric generator is the standard way in which power stations generate electricity. In a conventional power station, water is turned to steam via the heat from burning coal, oil, or gas, while in a nuclear power station the heat is generated by the fission reaction in the core of the reactor. Steam turbines are also used in a wide variety of industrial settings including steel works, mines, refineries, and lumber mills.

In a combined cycle power plant (CCPP), a steam turbine is used alongside a gas turbine to generate additional electricity from the same amount of fuel. Firstly, gas drives a gas turbine which generates electricity. Then the exhaust heat from this turbine is used to create steam that in turn drives a steam turbine and so generates further electricity. In the CCPP at Riverbay Co-Op City in New York, USA, for example, a combination of two gas turbines and one steam turbine produces 40 MW of electrical power which provides electricity, heating and cooling (via steam driven absorption chillers) for 60 000 local residents (see figure 2.4).

Figure 2.4. The combined cycle power plant at Riverbay Co-Op City in New York, USA. (Courtesy of Siemens. © Andreas Messner. Reproduced with permission. www.siemens.com/press)

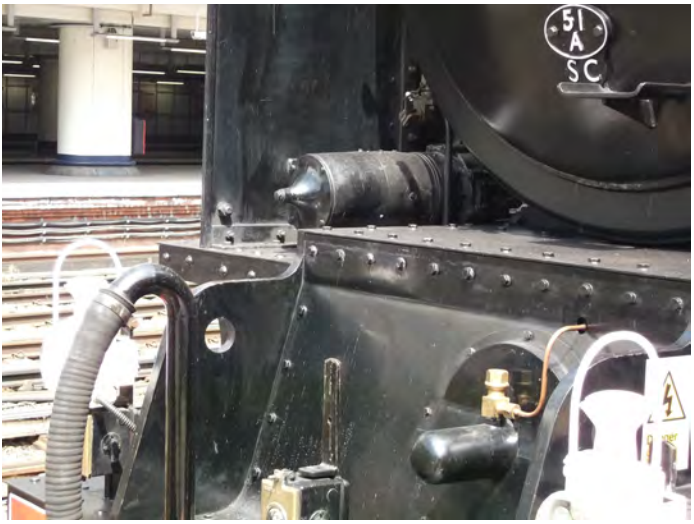


Figure 2.5. View of *Tornado* from the front showing the cylindrical steam turbo-generator to the left of the smokebox door. (© Sharon Ann Holgate, 2016.)

tender axles) that we use 30 A from,' explains Rob, adding that this alternator can generate up to 200 A and is the same type of alternator that most heritage coaches from the 1940s, 50s and 60s use to generate their own power for lighting. Their third way of charging, he continues, is to plug in a shore [off-board] power supply which will run off 110 V or 240 V mains when the locomotive is stationary in a depot.

To guard against supply failure, *Tornado* has two completely separate power supplies, each of which can run the entire electrical system. Each supply has a battery (with 12 hours of life fully charged) housed in a box underneath the cab, a battery charger and a control panel. Under normal operation, the Essential Services Supply—which has its control panel on the driver's side of the cab—powers headlamps, marker lamps, the GSM-R radio, OTMR and TPWS (see figure 2.6(a)). Meanwhile the control panel for the Auxiliary Services Supply is mounted on the fireman's side. This supply powers auxiliary equipment including cab lighting and lighting under the frames.

When it came to installing *Tornado's* electronics, Rob says that whilst starting from fresh made it easier to fit the electronics neatly in compared with retro-fitting systems onto a heritage locomotive, it was still a big challenge finding room for everything. So some ingenious places have been used. For instance, 'the main systems, including the control panels for the TPWS and OTMR, are mounted underneath the driver's and fireman's seats,' he says. (Figure 2.6(b) shows electric cabling tucked out of sight.)

In contrast to the 1950s oil lamps carried by the original A1s, *Tornado* has state-of-the-art LED headlamps and tail lamps (see figure 2.7). The headlamps—containing an array of 7 high brightness LEDs, small marker lights (that can be used to show train headcodes), and tail lamps were designed by optical engineer Alan Green. (See box 2.2 for more on LEDs, and box 2.3 for further details about *Tornado's* lights.)

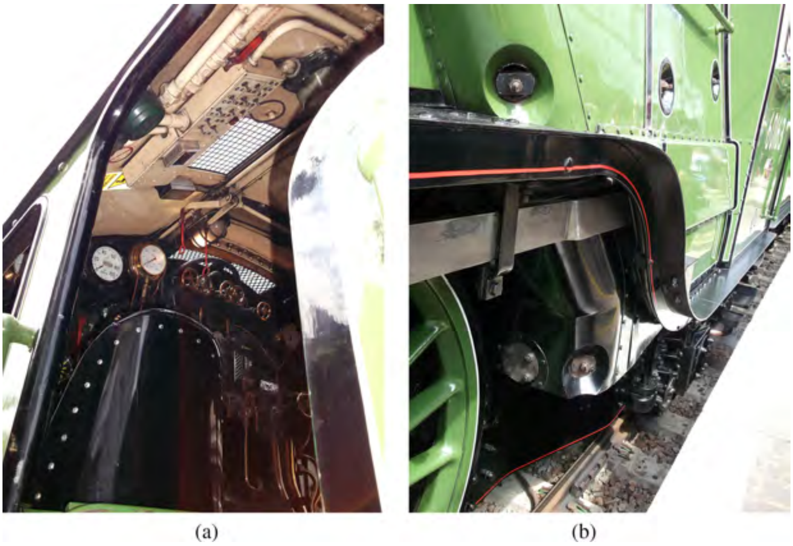

(a) (b)

Figure 2.6. (a) The Essential Services Supply which powers *Tornado's* headlamps, marker lamps, the OTMR and TPWS has its control panel mounted inside the roof on the driver's side of the cab; (b) electric cabling tucked out of sight under the locomotive's frames. (© Sharon Ann Holgate, 2016.)

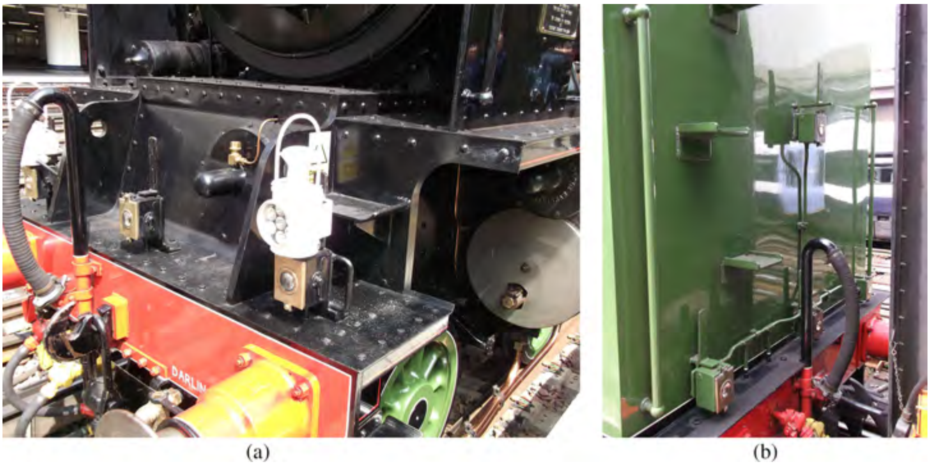
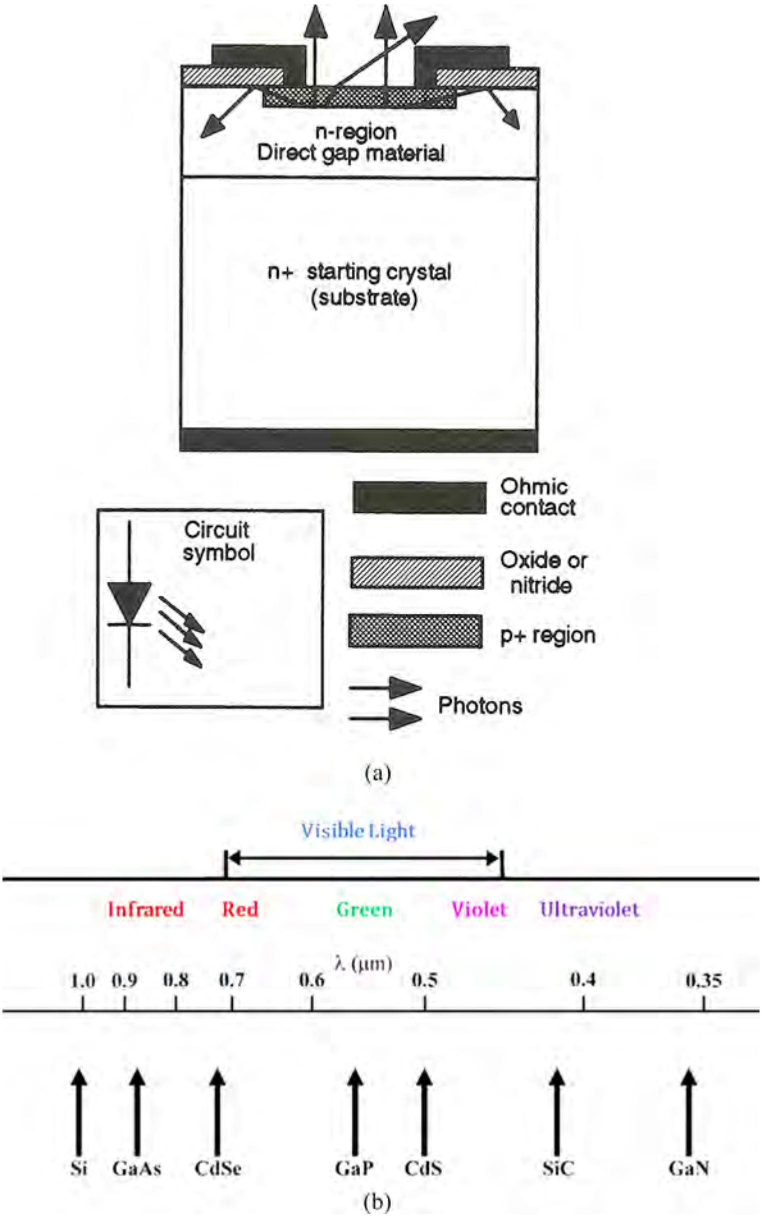

(a) (b)

Figure 2.7. (a) *Tornado*'s two headlamps (in the white casings) each contain 7 LEDs. Each headlamp works independently of the other. During the day, the left-hand lamp is used. This is much brighter than the night-time headlamp on the right so it can be easily seen by any track side workers. Three of the four front marker/tail lights can also be seen, two of which sit under the headlamps; (b) the four marker lights on the rear of the tender. The left and right lights are combined marker/tail lamps, displaying either a red or white 'aspect' (colour of a railway light). The two in the centre are white marker lamps. (© Sharon Ann Holgate, 2016.)

To keep *Tornado's* electrical system in good working order there is a detailed schedule of maintenance and checks. Some of these examinations are conducted by external examiners for the companies who operate steam on the UK mainline, whereas others are carried out in-house. Every six months, Rob conducts a thorough

Box 2.2. LEDs

Light emitting diodes (LEDs) are commonly used in a range of familiar applications including small indicator lights on electrical and electronic devices, and as an alternative to incandescent bulbs for domestic lighting.



(a)

(b)

Figure 2.8. Physics of LEDs. (a) The structure of an LED. (Republished with permission of Taylor & Francis, from *Introductory Semiconductor Device Physics*, Greg Parker, © 2004.) (b) The wavelengths of light emitted by several semiconductor materials that can be used to make LEDs.

Figure 2.8(a) shows the main parts of an LED. Near the top of the device there is a p–n junction which consists of a layer of p-type semiconductor (illustrated as lined and crosshatched regions) sandwiched next to a layer of n-type semiconductor. Both p-type and n-type semiconductors are created by deliberately adding atoms of another material to the semiconductor in a process known as doping.

If the dopant atoms contain fewer electrons than those of the semiconductor they are going into, this creates empty energy states known as 'holes'. A hole can be thought of as a particle with a positive electric charge the same size as the negative electric charge on an electron. Holes can contribute to the flow of electric current in a semiconductor by moving along in the opposite direction to electrons. So this type of doping produces a p-type semiconductor that conducts electricity via positively charged holes. Conversely if the dopant atoms contain more electrons than the atoms of the host semiconductor, an n-type semiconductor is created that conducts electricity via negatively charged electrons.

To create light, a p–n junction is forward biased. In other words it is connected up to an electrical circuit such that the positive terminal of the voltage supply is connected to the p-type semiconductor, and the negative terminal to the n-side of the p–n junction. This causes lots of electrons to diffuse into the p-side, where they recombine with holes. At the same time holes diffuse from the p-side into the n-side and recombine with electrons in the n-side. Recombination can be thought of as an electron disappearing into a hole. In terms of charge, the electron and hole effectively join together and cancel each other out. This recombination will produce photons, and the greater the current, the brighter the light emitted.

The colour of the emitted light is dependent on which semiconductor is used to make the LED. Figure 2.8(b) shows the wavelengths of light emitted by several semiconductor materials that can be used to make LEDs.

check of the electrical system, including taking covers off panels and tops off conduit boxes and clearing out the coal dust and water that can accumulate (see figure 2.9). Keeping everything clean is his biggest challenge, not least because wet coal dust is a conductor.

The A1 Trust are currently building a new version of Britain's most powerful passenger steam locomotive ever—the LNER Gresley class P2. The new engine, No. 2007 *Prince of Wales* (see figure 2.10 for an artist's impression of the completed locomotive) will have some features common with *Tornado* including the tender, firebox, and boiler—echoing the original P2s and A1s for which these features were the same or almost identical—as well as a similar electrical system (see figure 2.11). This will include LED head and tail lamps, the OTMR, and the TPWS which will be followed by its future ERTMS replacement. In addition, the electrical systems of both locomotives have the ability to allow temporary installation of various electronic safety systems that are used by other countries if they ever run on those countries' mainlines.

To avoid water and coal getting into and around sensitive equipment as it has on *Tornado*, Rob says the P2 will carry some of this equipment on the rear of its tender rather than on the engine itself. They also intend to use IP 66 and IP 67 die-cast

Box 2.3. Tornado’s lights

Tornado has four marker lights at its front (see figure 2.7(a)) as well as four marker lights on the rear of its tender (see figure 2.7(b)). Two of the lights from each set of four are combined marker/tail units containing one red and one white LED. The two LEDs are mounted inside the units such that an optical component known as a beam splitter enables light from either the red or the white LED to be emitted from the lamp. When the marker/tail lights are being used in their marker function they shine white, but when they are in their tail function ‘they are like tail lights on a car and shine red,’ explains Alan Green who designed *Tornado’s* lights and who until his recent retirement was an optical engineer for technology management and product development company Sagentia.

When the locomotive is moving forwards, the marker/tail lights at the front are set to white while those positioned at the rear of the tender are set to show red. Conversely, when the locomotive is reversing, these light colours are swapped over.

‘In the old days those lights would have had a conventional bulb in them. The driver would have got out of his cab and reconfigured the lights by flipping a lever that put a red filter in front of the lamp. The advantage that we have with LED lamps is that we’ve built a white LED and a red LED into those marker/tails, and the lamp can be switched into its marker or its tail configuration just by the flick of a switch from the cab,’ says Alan, who met Rob Morland when they were both working for Sagentia.

Tornado’s two headlamps (in the white casings in figure 2.1(a)) work independently of each other. ‘Each headlamp contains 7 LEDs which are about 3 W each of electrical input. So you’ve got just over 20 W of electrical input and they’re giving you a brightness that would take well over 100 W to achieve via conventional methods. It’s not so much power being drawn off, and in situations where they are running [the locomotive] on the batteries obviously they can run for longer without having to worry about charging,’ explains Alan, adding that another advantage is the lifetime of LEDs which is significantly greater than that of conventional bulbs.

During the day, the left-hand headlamp is used. This is much brighter than the night-time headlamp on the right so it can be easily seen by any track side workers. Although steam locomotives working on the UK mainline are allowed to use battery-powered portable headlamps up to 75 mph (see section 2.3) because the A1 Trust aims to run *Tornado* at 90 mph, its headlamps meet the required standards for any mainline locomotive running above 60 mph.

While the use of 7 LEDs fulfils the brightness requirements for the headlamps, the light beam emitted also needs to be a specific shape. ‘The shape of the reflector [a curved surface positioned directly behind the light] is what sets the beam angle that comes out. If you just had an LED with no reflector it emits its light over a very wide angle, which is no use if you want to make a headlamp. You want to collect all that light and shine it in a particular direction,’ explains Alan, adding that it was not possible to simply go out and buy a reflector that produced the narrow beam *Tornado* required.

‘But it turned out reflectors Sagentia had designed for Brandon Medical for use in operating theatre lights gave a beam divergence very close to that needed for *Tornado*, hence we could use those reflectors,’ continues Alan. ‘However the reflectors on their own would not allow us to meet the specifications as they produce a symmetrical beam—so the beam’s divergence (that is, how much the beam spreads) is the same horizontally as it is vertically. For the specification we want it to spread more horizontally than it does vertically. We’ve achieved that for *Tornado* by cementing to the front of three out of the seven reflectors [in each headlamp] a glass cylindrical diverging lens that spreads the light horizontally just enough [to comply with the specifications].’

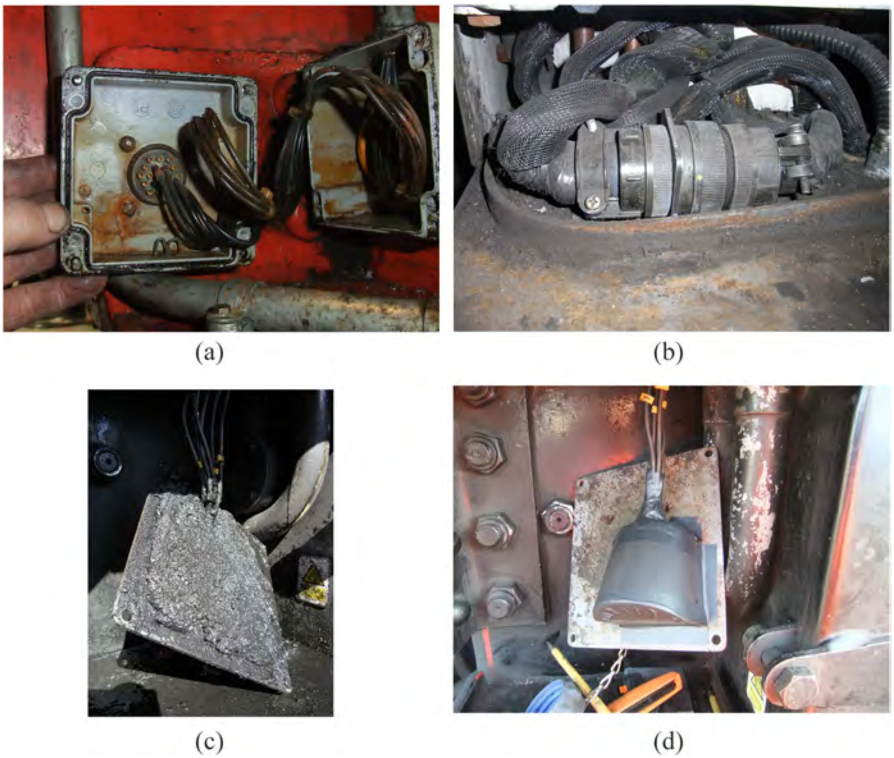

(a) (b) (c) (d)

Figure 2.9. Cleaning and testing *Tornado's* electrical system. (a) Rust inside a conduit box that has previously filled with water. A small hole was drilled in the base of the box to prevent this problem in the future; (b) Coal dust around military connectors; (c) 'before': wet coal dust on a connector; (d) 'after': electrical tape provides an effective but low tech solution for protecting the connector from wet coal dust. (© Rob Morland, A1SLT. Reproduced with permission.)

aluminium boxes to house some of the components which, as table 2.1 in box 2.4 shows, will keep out wet coal dust.

Prince of Wales will also have a structured trunking system made out of box trunking and halogen-free plastic-covered steel flexible conduit, rather than galvanised steel conduit as on *Tornado*. This will make it easier to accommodate extra cabling when required, so giving the system room for adaptation and modernisation.

The work Rob and the other A1 Trust volunteers have done on *Tornado's* bespoke electrical system—including the preparatory work ready for installing the ERTMS—has not only helped them design the system for their new P2 locomotive. It is also set to benefit heritage steam locomotives, as the next section reveals.

2.3 Electronics on-board a heritage steam locomotive

Any steam locomotive hauling passengers must carry modern safety equipment if it runs on the main line, says Martyn Bane, Deputy Engineer with the 6024 Preservation Society Ltd which maintains the heritage ex-Great Western Railway

Figure 2.10. Artist's impression of LNER new build P2 No. 2007 by Jonathan Clay. (Reproduced by permission of Mark Allatt, A1SLT.)

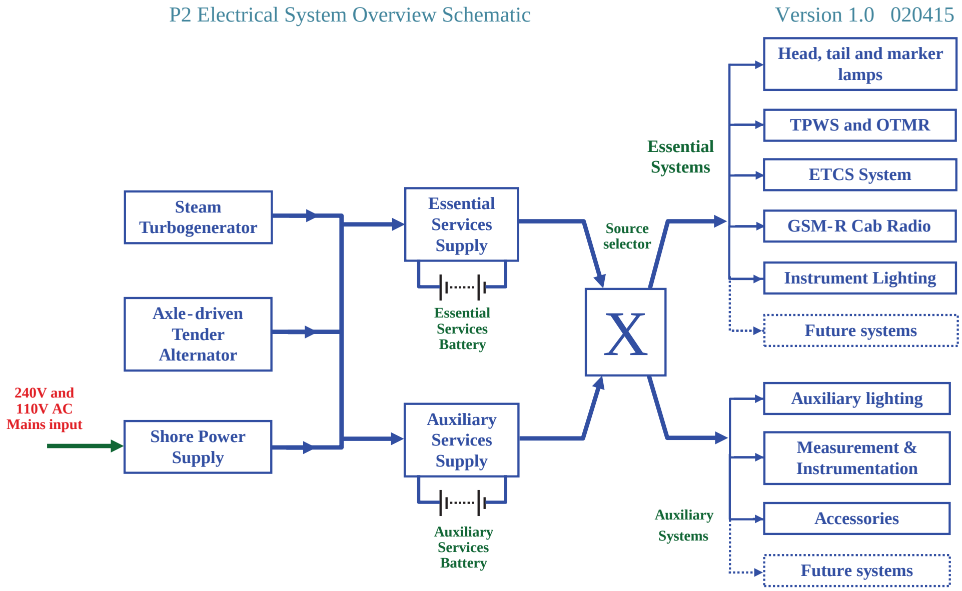


Figure 2.11. An overview of the P2 electrical system. (Courtesy of Rob Morland. © P2 Steam Locomotive Company 2015. Reproduced with permission.)

Box 2.4. IP ratings

IP, or Ingress Protection, ratings (see table 2.1) are two-digit codes that indicate the level of protection the enclosures surrounding electrical components or apparatus provide. The first digit indicates how much protection the enclosure gives hazardous parts of the components or apparatus against access by solid objects. The second digit represents the extent to which the enclosure prevents water penetration.

Table 2.1. IP ratings.

First Digit	Mechanical Protection	Second Digit	Water Ingress Protection
0	No protection	0	No protection
1	Protected against solid objects over 50 mm, e.g. accidental touch by hands	1	Protected against vertically falling drops of water e.g. condensation
2	Protected against solid objects over 12 mm, e.g. fingers	2	Protected against direct sprays of water up to 15° from the vertical
3	Protected against solid objects over 2.5 mm, e.g. tools and wires	3	Protected against direct sprays of water up to 60° from the vertical
4	Protected against solid objects over 1 mm, e.g. wires, nails etc	4	Protected against water splashed from all directions, limited ingress permitted
5	Protected against dust limited ingress, not harmful deposits	5	Protected against low pressure jets of water from all directions, limited ingress permitted
6	Totally protected against dust	6	Protected against strong jets of water e.g. ship's deck, limited ingress permitted
		7	Protected against the effects of temporary immersion between 15 cm and 1 m. Duration of test 30 minutes
		8	Protected against long periods of immersion under pressure

(GWR) King class steam locomotive number 6024 *King Edward I*. The locomotive, which is owned by the Royal Scot Locomotive & General Trust, is now mostly used for hauling steam excursions on the UK's mainline (see figure 2.12), but also runs on preserved steam railways.

This safety equipment must, of course, be kept in perfect working order. So in addition to the stringent annual external examination, every time a steam locomotive is used for a mainline journey it must first pass a 'fitness to run' examination. These examinations are carried out by inspectors from one of the two train operating companies that oversee steam operation on the UK mainline: DB Cargo or West


(a) (b)

Figure 2.12. GWR King class locomotive number 6024 *King Edward I* hauling mainline steam excursions on ex-GWR territory. (a) Passing through Bradford on Avon station in Wiltshire, UK. (© Tony Sparkes. Reproduced with permission.) (b) Passing through Bishops Lydeard in Somerset, UK in 2009. (© Martyn Bane. Reproduced with permission.)

Coast Railways. Their inspectors will check both the mechanical and electronic features of the locomotive, and only if it passes all the checks will it be allowed to run on the mainline.

At the time of writing this book, Martyn is working as part of a team on 6024's overhaul—which includes an upgrade of the on-board electronics. The engine was built in 1930, and hauled express passenger services until it was withdrawn from British Railways (BR) service in 1962. (BR was formed in 1948, and had inherited the locomotive from the GWR.) During its original working lifetime 6024 clocked up over one and a half million miles of running. The 6024 Preservation Society Ltd saved the locomotive from Woodham Brothers scrapyard in Wales in 1973, and gradually restored it to mainline condition, where it resumed running in 1990. It was bought by its current owners the Royal Scot Locomotive & General Trust in 2011. (Figure 1.2 shows the engine hauling a steam excursion on the mainline in 1995.) 'The engine carried no electronics until 1994 when the forerunner of the Train Protection and Warning System (TPWS)—known as the Automatic Warning System (AWS)—was fitted,' says Martyn. The AWS, he explains, enabled the locomotive to run up to 75 mph on the UK mainline and was a 1950s technology used by British Railways on its steam locomotives, and its diesel and electric trains.

In 2004, during a previous overhaul, 6024's AWS was replaced with TPWS, and a transformer (see box 2.5) was used to step the voltage down from the 36 V used by AWS to the 24 V needed for TPWS. (The TPWS system fitted also incorporates the AWS system functions but in modern electronics, so as with all modern trains, 6024 effectively carries AWS and TPWS.) The TPWS control panel and main wiring (see figure 2.13) sat in a box underneath the driver's seat, continues Martyn, adding that although not every part of the electrical system can be tucked completely out of sight, they avoid bolting on new equipment in very obvious positions. 'We're running a machine that was built in 1930 and whilst we accept that if we want to run on the mainline compromises have to be made, we try and maintain the historical look by positioning the electronics in as sensitive a way as possible.'

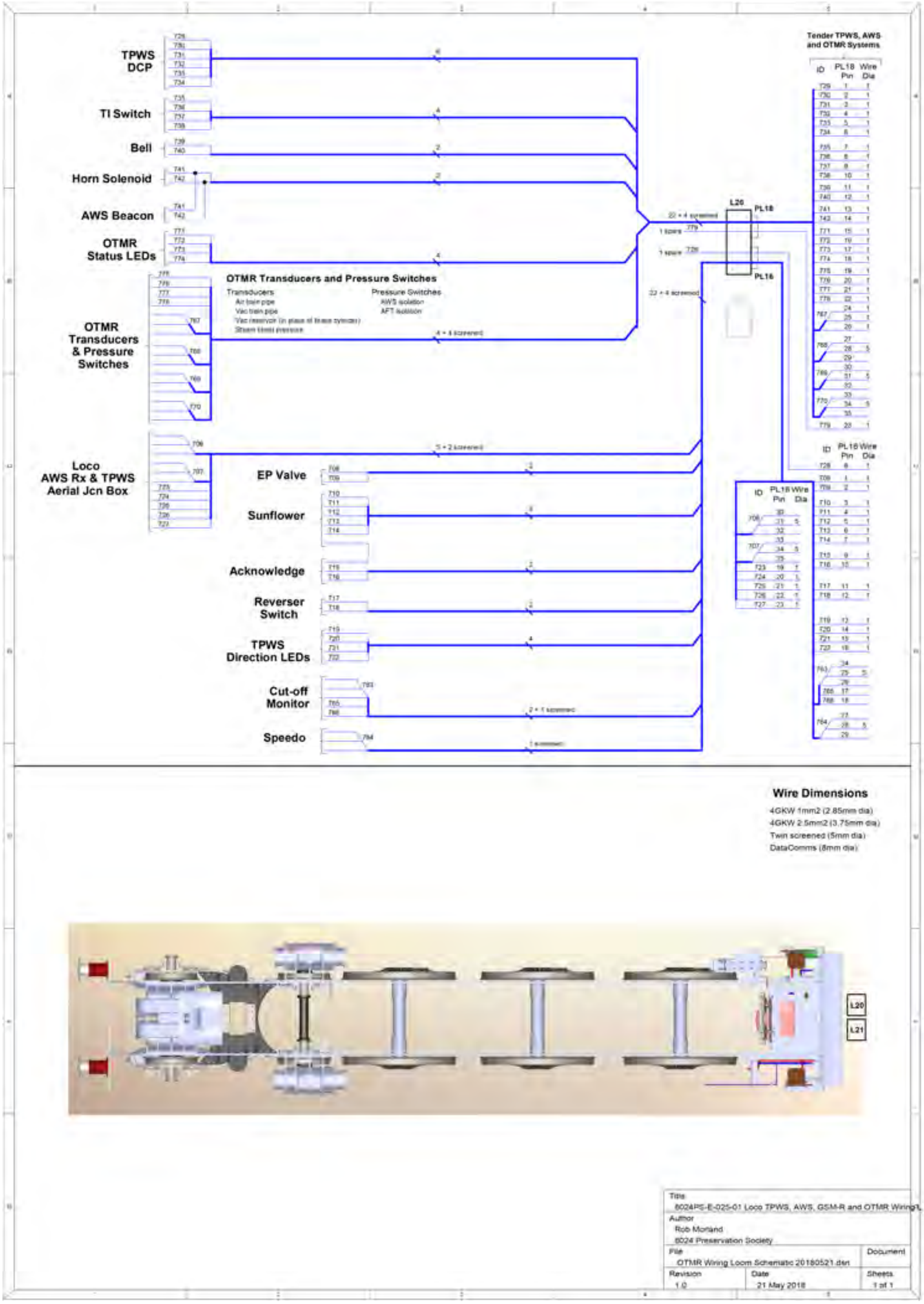


Figure 2.13. Schematic diagram of wiring for equipment including the TPWS, AWS, GSM-R and OTMR on locomotive 6024. (© 6024 Preservation Society Ltd. Reproduced with permission.)

Box 2.5. Transformers

Transformers convert one voltage into another thanks to electromagnetic induction. This effect was independently discovered by the American physicist Joseph Henry in 1830 and British scientist Michael Faraday in 1831.

Transformers consist of two coils of wire wound around an iron, steel, or ferrite core. The AC (alternating current) electricity that needs its voltage to be changed flows into the 'primary' coil creating an alternating magnetic field. This magnetic field induces AC in the nearby 'secondary' coil. If the secondary coil has fewer turns of wire than the primary coil, the voltage of the induced AC is less than that of the original AC. This type of transformer is known as a 'step-down' transformer as it reduces voltage. Figure 2.14 illustrates a step-down transformer.

Conversely in a 'step-up' transformer, which increases voltage, there are more turns in the secondary coil compared with the number in the primary coil. This means the induced AC in the secondary coil will have a higher voltage than the original AC electricity flowing in the primary coil.

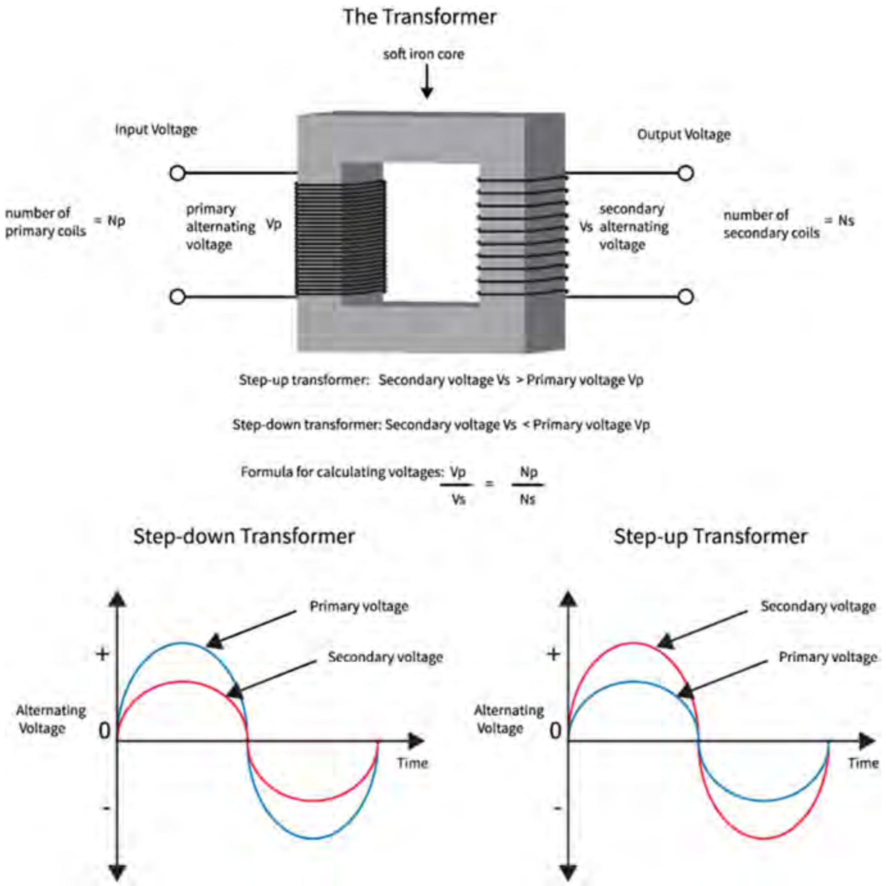


Figure 2.14. A 'step-down' transformer. (© Steve Cymro/Shutterstock.com.)

To fulfil safety regulations, an On Train Monitoring Recorder (OTMR) was fitted a few years later, under the chassis of the tender so it would have the greatest chance of survival in the event of a major accident. Whilst the OTMR is primarily a data recording system, whenever the locomotive carries out a mainline trip, Martyn downloads the data from it onto a laptop. This, he says, helps him analyse the performance of the locomotive, and so make any adjustments as required. He can also check whether the transducers that convert analogue signals such as steam pressure into digital inputs for the OTMR have filled with water or not.

For mainline running, steam locomotives must also carry one electrically lit headlamp when leading a train, says Martyn. 'This is generally a battery powered portable lamp fitted with a halogen bulb [see figure 2.15] which meets the requirements for running up to 75 mph. The same lamps can be used on modern trains for running to 75 mph but are generally only used in the event of a fixed headlamp failing. To run faster than 75 mph requires a more powerful fixed headlamp—no portable lamp meets the requirements, in large part due to the positioning of the beam required by the applicable standards—and an additional low intensity marker lamp which is generally on the opposite side to the main headlamp. The main headlamp also needs to be of variable brightness [to allow] for day and night time operations. The other requirement on a train is for a red tail lamp.' If this tail lamp is portable it must constantly flash, or if it is a fixed lamp it must emit a continuous beam, he explains, adding that when 6024 comes back into service it will carry a pair of new headlamps—contained within modified paraffin lamps to maintain the period look—that will each be able to run both headlamp and marker functions.

The current overhaul involves a complete redesign of all 6024's electrical systems with the help of Rob Morland from the A1 Trust (see figure 2.16 for a schematic diagram of the electrical system). This overhaul will include upgrading 6024's components to versions better suited to the harsh environment of a steam locomotive in an effort to reduce maintenance, moving as many systems as possible from the cab onto the tender to decrease the amount of vibration the electronics is subjected to, and improving battery life. As on *Tornado*, 6024's new system will contain two sets of batteries to ensure resilience of supply, explains Martyn. 'If we have a set go down we can just flip over to the other set, using Rob's electronics,' he says.

The 6024 Preservation Society will also include some empty conduit that can accommodate any systems—such as the European Railway Traffic Management System (ERTMS)—which need adding in the future, says Martyn (figure 2.17 shows conduit being fitted during the locomotive's overhaul). This future proofing of 6024's electrical system, together with the electronics it will carry, should then enable people to enjoy travelling behind this painstakingly restored survivor from our past for many more years to come.

2.4 Keeping a 1960s diesel shunter on track

From the mid-1950s to the early 1960s British Railways built over 1000 diesel electric shunting locomotives based on 1940s prototypes built by the LMS (London

Figure 2.15. Locomotive 6024 *King Edward I* at Paignton in Devon. Pictured on the right of the photograph at the front of the locomotive is a battery-powered headlamp with a halogen bulb. This is fitted inside the casing of a portable vintage oil lamp similar to the lamps the locomotive would originally have used. A traditional paraffin lit lamp is on the left of this photograph. The two lamps to the side, sitting up on the running plate, are spares which were traditionally carried in that position. (© Martyn Bane. Reproduced with permission.)

Midland and Scottish Railway) who had been experimenting with diesel power since the 1930s. These locomotives were designated Class 08 and Class 09, (and using different suppliers of engines and electrical equipment Class 10). While identical looking at a glance, the main difference between Class 08 (see figure 2.18) and Class 09 locomotives (see figure 2.19) was the speed they could reach—15 mph (24 kph) for the Class 08, and 27 mph (43 kph) for the Class 09. While early versions used 90 volts direct current (DC) for auxiliary systems, later builds standardised on 110 volts DC.

They contained six-cylinder English Electric engines capable of generating 350 h.p. and in some cases 400 h.p. (See box 4.1 for more on horsepower.) The English Electric Company, which was founded in 1918 and eventually became part of The General Electric Company (GEC) in 1968, built a range of diesel and electric locomotives including the Deltic locomotive for British Railways which replaced some of the most iconic express passenger steam locomotives.

Prior to its 2016 withdrawal from service as part of train operator Southern's fleet, diesel electric shunter number 09026 had for several years carried out various shunting duties at the Lovers Walk depot just north of the mainline terminus at Brighton on the UK's south coast. The locomotive is now owned by the Tunbridge Wells & Eridge Railway Preservation Society, and at the time of writing this book is

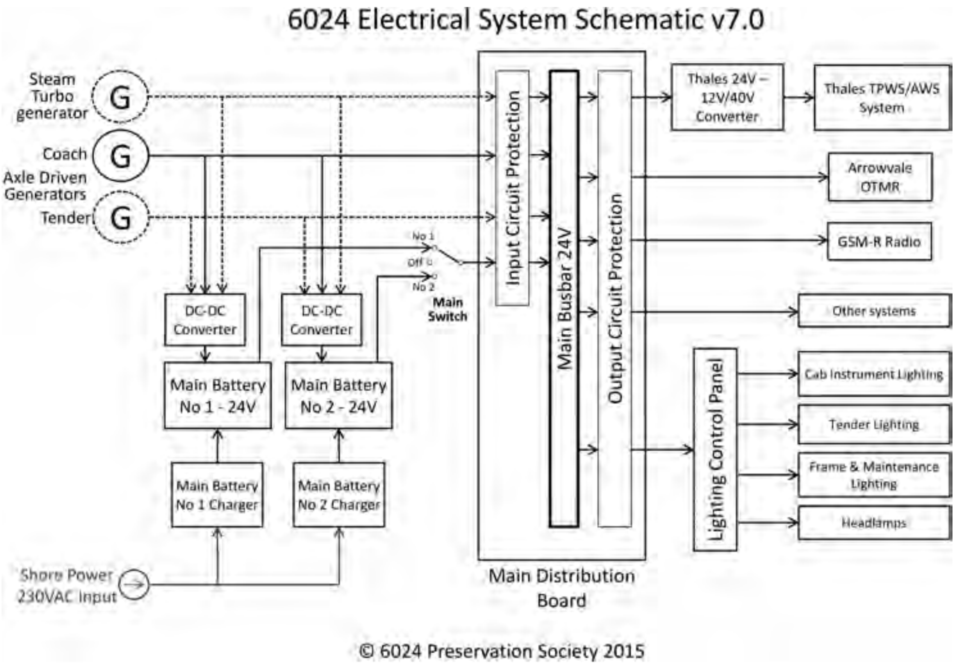


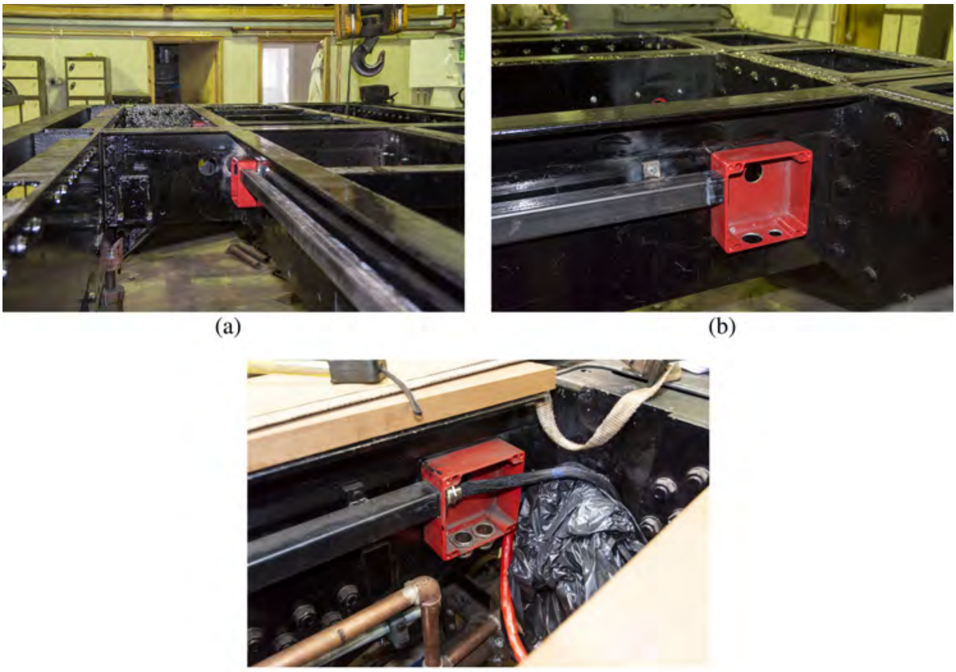
Figure 2.16. Overview of the electrical system for locomotive 6024. (© 6024 Preservation Society Ltd 2015. Reproduced with permission.)

undergoing an overhaul at the heritage Spa Valley Railway in Kent. (The Spa Valley Railway also has an example of a 1950s Class 10 in service.) Shortly after 09026 arrived at the Spa Valley in May 2016, it was withdrawn from service.

‘The main reason it was taken out of service is that its original main generator has dead segments on the commutator. We are replacing the main generator with a freshly overhauled one,’ explains Jonnie Wesson, General Manager of the Spa Valley Railway, adding that he expects the locomotive’s future duties to include not only shunting but also running occasional passenger trains on preserved lines. (See box 2.6 for more on DC generators.)

‘The electrical system is the same as when built. It is very simple electrics created in the 1960s for use in the Class 08 and 09 locomotives—it probably pre-dates this too. 09026 was one of the 110 V DC auxiliary system locomotives powered from an auxiliary generator and a 750 V main generator which are directly coupled to the engine’s crankshaft,’ continues Jonnie.

‘It is started off of batteries (110 V) which spin the generator, acting as a motor. This turns over the diesel engine which then fires and takes over. The batteries are then recharged from the auxiliary generator. Once it is running, to turn the wheels there are a pair of traction motors on the outer axles at each end of the locomotive. [The middle set of wheels is not connected to a motor.] These traction motors receive traction current and voltage from the main generator up to 750 V and their output is controlled by varying the resistance and speed of the generator. The current can vary



(a) (b)

(c)

Figure 2.17. Conduit installation on the frames of GWR King Class locomotive 6024 *King Edward I*, shown during the major overhaul of the locomotive. (a) Working on the conduit for housing 24 V power cabling in 2016; (b) a 2016 view of the steel box section used as conduit and a pre-drilled Rose box (a robust diecast box). The hole in the rear of the box is to accommodate flexible conduit from the other side of the chassis, while the holes at the bottom are for flexible conduit to the front of the chassis and the electrical systems; (c) a 2018 view of the area shown in (b) now with cables pulled through the conduit, an extra piece of conduit below for safety systems—which has to be physically separated from the power supply—and copper pipes installed for the braking system. (© Martyn Bane. Reproduced with permission.)

dependent on the load of the train it is pulling but the 1 hour continuous rating of the main generator is around 600 amperes (A). Some of our bigger diesels will manage 3000 A on pull away with a heavy train,' he says.

Perhaps surprisingly there is no back-up system in place to cover in the event of a power failure. 'If any of the electrical system that controls ancillaries—such as the air compressor or the main traction system—fails then the locomotive is deemed a failure and can't then operate until repaired,' explains Jonnie.

As with steam locomotives, the environment on-board vintage diesel locomotives presents challenges when it comes to keeping the electrical system running, as Jonnie reveals. 'Condensation from the outside world is the killer for these 50–60 year old locomotives. The damp in the generators can cause the generators and traction motors to short circuit (flashover).' To prevent this, heaters are installed in the electrical area of the locomotive.

Since 09026 will not be running on the mainline it does not need to carry TPWS and OTMR, or require facilities for carrying future versions of these systems.

Figure 2.18. A restored 1962 Class 08 diesel shunting engine at Okehampton Station on Dartmoor, Devon, UK. (© Peter Turner Photography/Shutterstock.com.)

Figure 2.19. Class 09 shunter number 09026 hauling a passenger train made up from heritage BR grey and blue liveried coaches at Tunbridge Wells West station on the Spa Valley Railway. (© Charlie Ralph. Reproduced with permission.)

Box 2.6. DC generators

A generator that produces direct current (DC) electricity is known as a dynamo (see figure 2.20). The DC, which only flows in one direction, is induced in a coil of wire known as an armature that rotates inside a magnetic field. This magnetic field is created by a permanent magnet in the generator.

As the armature rotates, one side will move past the south pole of this permanent magnet. Electromagnetic induction induces an electric current flowing in one direction in the armature. As the armature continues rotating it will then pass the north pole of the permanent magnet. This induces an electric current flowing in the opposite direction to that induced by the south pole.

A device known as a commutator ensures that the electric current leaving the generator only flows in one direction. A commutator is a contact ring with a gap in it such that it only connects the generator to an external electric circuit for every half turn of the armature. The resulting electric current is therefore a series of electrical pulses flowing in one direction—in other words DC.

In some dynamos there are several coils of wire each housed within an individual slot in the armature and insulated from one another. In this case the commutator consists of several segments. Each coil of wire has a corresponding pair of commutator segments that enable DC to be produced by the dynamo.

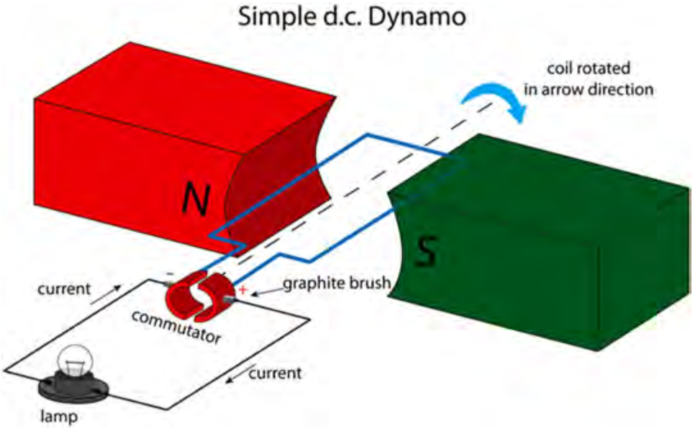


Figure 2.20. The main features of a simple DC generator, also known as a dynamo. (© Steve Cymro/ Shutterstock.com.)

It might acquire one modern concession as far as the electrical system goes though. While at present the locomotive has standard filament lamps, ‘it will likely get LED equivalents when it comes back into service,’ says Jonnie.

2.5 The electrical system for a vintage railroad observation car

The design of the streamlined *Cedar Rapids* Skytop parlour lounge observation car (see figure 2.21) was created by Brooks Stevens (1911–1995), an American industrial

Figure 2.21. The *Cedar Rapids* Skytop parlour lounge observation car in its restored condition pictured on October 9, 2016 passing Bongards, Minnesota on its way to Winthrop from Minneapolis. (© Geoffrey Kuchera/Shutterstock.com.)

designer who designed over 3000 products ranging from corporate logos to home appliances. It was built in 1948 by the Milwaukee Road (Chicago, Milwaukee, St. Paul & Pacific) railroad company for use at the rear of their iconic *Hiawatha* streamlined trains. In addition to the 24 parlour chairs, which rotate and recline, there are a further 12 seats in the observation lounge area—known as the Skytop Solarium—at the far end of the car, which has windows in the ceiling as well as around the walls allowing full views of the surroundings including the sky.

Originally the car was pulled by Milwaukee Road steam locomotives and diesel electric traction, explains Steve Sandberg, President & Chief Operating Officer of the Minnesota-based non-profit organization Railroading Heritage of Midwest America who now own and operate the car. Today *Cedar Rapids*, which earns its keep via leasing and charter, is fully compatible with modern equipment and so can be hauled as part of any modern train on the American or Canadian railroad network.

Only four Skytop parlour lounge observation cars were ever built (see figure 2.22 for another of the four, pictured in service in 1964). While three of the four survive, *Cedar Rapids* is the only car still on the rails. It was in service from 1948 through to 1970 when it was donated to Brooks Stevens. After subsequently spending time in private ownership, in 1998 *Cedar Rapids* was acquired by volunteer group Friends of the 261 who are now part of Railroading Heritage of Midwest America. The Friends restored the car at their workshop in Minneapolis and returned it to service. Alongside refurbishing the interior—including the original woodwork and upholstery, and

Figure 2.22. Another of the four Skytop parlour lounge observation cars, *Coon Rapids*, in service in August 1964. (Photographer: Roger Puta. Public domain.)

adding modern safety features, heating, air conditioning and plumbing, this restoration included replacing the car's original electrical system, as Steve explains.

'The original electrical system was 32 volt DC. A small propane generator would power a large set of batteries that would operate the lights and AC. The old 32 volt DC system was unreliable and parts were not available. [So] the entire car was converted from 32 volt DC to 480 volt 3 phase AC in 2002.' This also enabled the equipment on-board *Cedar Rapids* to meet current railroad standards, adds Steve.

The observation car's electrical system is mainly used to power the internal heating, the fluorescent and incandescent lighting and the air conditioning. 'Currently the 480 volt AC electricity [that powers the electrical system] is provided from the locomotive,' says Steve, adding that there is also a 55 kW diesel back-up generator that can take over in the event of a power failure.

Further Reading

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Weblinks (live as at June 2018)

The A1 Steam Locomotive Trust
https://www.a1steam.com/
The A1 Tornado steam engine: riding the rails with the A1 Trust (E&T video)
https://www.youtube.com/watch?v=JFdIunghGlE
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http://www.royalscot.org.uk
The Spa Valley Railway
http://www.spavalleyrailway.co.uk/
Cedar Rapids observation car
https://261.com/fleet/cedar-rapids/

Chapter 3

Driving force—the physics of sports cars

3.1 Introduction

Whether we are driving sport cars, watching our favourite motorsport, or just drooling over supercars, we will probably consider some of the engineering behind the cars, and acknowledge the technical know-how the teams need to enable competitive racing. But we are unlikely to give much thought to the detailed physics and materials technology that goes into the design and construction of these high-performance motor vehicles. However physics, and materials choice, play a large part in creating the performance and handling characteristics that mark these cars out compared with the vehicles that most of us drive.

In this chapter we will first look at some of the physics and materials technology used to create the *Elemental Rp1*—a road legal track day car launched in 2016 that was designed by a team of ex-F1 engineers. Peter Kent, Composites Director for the Elemental Motor Company, which was founded in 2012 and is based in Hampshire in the UK, will explain the physics and technology they employed, and the mix of materials that go into the *Rp1*'s construction. In addition, Mark Fowler, Elemental's Aerodynamics and Body Engineering Manager, describes the *Rp1's* Le Mans-style underfloor aerodynamics.

We will then learn about the role modern materials play in creating the supercars produced by Swedish bespoke manufacturer Koenigsegg Automotive. As with the *Elemental Rp1*, I first wrote about Koenigsegg supercars in 2017 for a feature on the materials used in bespoke sports cars and supercars for *Materials World* magazine, which forms the origin for this chapter. Here, Steven Wade, Manager, Communications and PR for Koenigsegg reveals how the lightweight materials chosen help create not only the stunning body shapes but also the extraordinary speed and handling.

3.2 Designing and creating a track day car

For the team behind the *Elemental Rp1*, physics and materials science have been an integral part of creating their car, which takes just 2.7 s to go from 0–60 mph

doi:10.1088/978-1-64327-270-2ch3

Figure 3.1. (a) and (b) The *Elemental Rp1*. The car takes just 2.7 s to go from a standstill to 60 mph. (© Elemental Cars Ltd. Reproduced with permission.)

(0–97 kph) and is designed to be both a track day car and a road going vehicle. (See figures 1.3 and 3.1.)

As Peter Kent, Composites Director for the Elemental Motor Company, explains, the original idea for the *Rp1* came back in 2007 from the Founder and Technical Director of Elemental John Begley, who was then his colleague at McLaren F1. 'John had been to a few track days, seen what was on offer and basically thought someone could do something better,' says Peter. A third McLaren colleague, Mark Fowler, who is now Elemental's Aerodynamics and Body Engineering Manager, had already joined forces with John to start developing some ideas for the car as had Guy Colborne, now Elemental's Design Manager and a visiting lecturer at the Royal College of Art on the Vehicle Design course, when Peter became involved with the project too.

Peter had studied composites engineering at Plymouth University. His 4 year degree incorporated a sandwich year at British Aerospace working on the A380 composite wing programme, and a year studying at the University of Victoria in Canada. His degree included modules in mechanical engineering as well as composites. One of the triggers for entering his future career, recalls Peter, was a visit from a McLaren employee in a McLaren F1 road car whilst he was at Guildford College taking a BTec in engineering prior to university. 'This was a great inspiration. I was fascinated by it and it certainly sparked something inside me.'

'I'd always been interested in motor sport. I converted my car into a rally car when I was 17, and whilst I was in my final year at university I was fortunate enough to get a job at the Toyota Formula 1 team in Cologne [in Germany] as a junior composites designer. I learned a lot there,' he continues. After nearly three years in that role, Peter returned to the UK to take up a position in the McLaren F1 team. 'I tried to go around as many different groups as I could—composites gearbox, composite suspension, bodywork, chassis—to learn as much about the car as possible and get as much experience as I could.'

'I then moved over to McLaren automotive where John [Begley] and I were the first two [engineers] to work on the McLaren P1™ [road car]. We were working for the chief designer Dan Parry-Williams and it was almost a clean sheet of paper,

Figure 3.2. The feet-up driving position in the *Elemental Rp1.* This feature is a first for a road car, and was defined by the positioning required for parts of the underfloor aerodynamics. (© Elemental Cars Ltd. Reproduced with permission.)

which was fantastic. It meant [we were] coming up with new ideas and new concepts, and looking at hybrid technology as well. After a couple of years I joined the hybrid group to help develop the battery pack for the P1,' continues Peter, who left McLaren in 2012 to join John and Mark who had recently quit their jobs and set up the Elemental Motor Company to focus on developing the *Rp1* and bringing it to market.

While the original concept for the *Rp1* remained fixed—including the F1 style feet-up driving position (see figure 3.2), and F1 and Le Mans inspired aerodynamics which had not been seen previously in a road car— the execution of that concept was a gradually evolving process, explains Peter. For example, figure 1.3(b) shows the first sketches of the *Rp1's* bodywork designed by Guy Colborne to fit around John and Mark's CAD drawings of the chassis and tub, and to fit stylistically with the concept for the car.

'Initially they weren't going to have a carbon tub, but when I came along looking at the composite side of things we realised that we could design and manufacture a carbon tub for this car rather than an aluminium one,' says Peter. 'We started looking down that route and it grew from there basically—building wooden seating bucks and aluminium prototypes, and just proving out processes and coming up with new ideas.'

'There was an awful lot involved in this project. But the car seems to be now doing exactly what we wanted it to do,' adds Peter, who works in his own design consultancy, Kove Design, alongside his role at Elemental.

The aerodynamics were initially tested via computational fluid dynamics (CFD) analysis and an *Rp1* prototype being subjected to wind tunnel testing at vehicle engineering test centre MIRA, as well as via experiments conducted on the road and track. To further develop the aerodynamics, the Elemental team collaborated with Mark Taylor at aerodynamic specialists London Computational Solutions (LCS).

Mark used a revolutionary CFD software package that modelled the air flow across the car so accurately that the optimisation of the design did not require wind tunnel testing (see figure 3.3). As a result of his analysis, adjustments were made to the chassis and powertrain, while the underfloor aerodynamics of the car was modified, as was some of the body work including adding a rear wing (which is likely to become an option in the future for race versions of the *Rp*1). These modifications enabled the

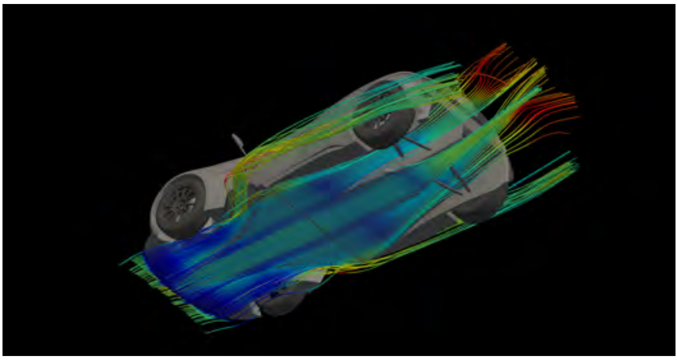

Figure 3.3. Modelling of the airflow underneath the *Rp1*. (© Elemental Cars Ltd. Reproduced with permission.)

Rp1 to generate 1 tonne of downforce (see box 3.1) at 150 miles per hour—the highest value of downforce ever seen in a road going vehicle. (See box 3.2 for more on the *Rp1's* underfloor aerodynamics.)

The significant downforce that the car can generate is 'something you have to be careful with,' explains Peter. 'A car that's heavily influenced by aero needs to be fairly benign on the road. You don't want to be driving around a corner and suddenly hit a pothole and the aero gets all upset, and your car becomes unbalanced. So you can't have anything that's too sensitive.' To avoid this, the team ensured that the aerodynamics was developed in such a way that there would be excellent handling while still getting extremely large amounts of downforce.

The shape of the 68 kg tub contributes to the *Rp1*'s overall low height of just 1070 mm (see figure 3.6), and minimises the front area. This enables air to flow smoothly along the upper body of the car. Despite being very low, drivers and passengers up to 6 feet 6 inches (1.98 m) tall can be safely accommodated.

Delivery of the *Rp1* to customers began in 2017. The car took a decade to go from the initial idea through to a production model, including full-time working for nearly six years before the car hit the market. This time was needed explains Peter, because it is so difficult to build reliability into a vehicle. 'You first get the fundamentals of reliability such as safety correct then work on the details.'

'Designing pretty much everything yourselves is a massive undertaking,' continues Peter. 'But as designers we have a good feel for what is right just through experience. There is no need to go through lots of FE (finite element) analysis loops because generally our initial design will be quite close to what you want, and it will just be small areas that might need modifying. For example more carbon might be needed in a particular area because of a stress concentration there.' (See box 4.2 for more on stress.)

The FE analysis allows different scenarios to be tested. For instance, how well the car can handle the load case (in other words the forces acting on it) when braking and cornering, or when braking and being bumped up and down by the road surface at the rear or the side. While FE analysis was carried out on some of the individual components that needed to withstand specific loads, most of the analysis looked at the forces acting on the car as a whole.

Box 3.1. Downforce

Downforce is a force acting in a downwards direction that pulls a car towards the road or track beneath it. Downforce can be created via upside-down aerofoils, or by a chassis design that channels air in a particular way. In both cases the air flow around the car is such that there is a lower pressure below the car than above it as it moves forward, which ‘sucks’ the car towards the ground.

This is the opposite effect to the lift created via the aerofoil shape of an aircraft wing. To create lift, the air needs to move faster over the top of the wing than underneath it as the aircraft moves forward through the air. It is the shape of an aerofoil (see figure 3.4) that causes this difference in air speed as the aerofoil moves through it—air is forced to take a longer path while passing over the top of the wing compared with air passing under the wing. As fast flowing air has a lower pressure than slow moving air, this creates a pressure difference between the top and bottom of the wing that results in a lift force acting upwards on the wing.

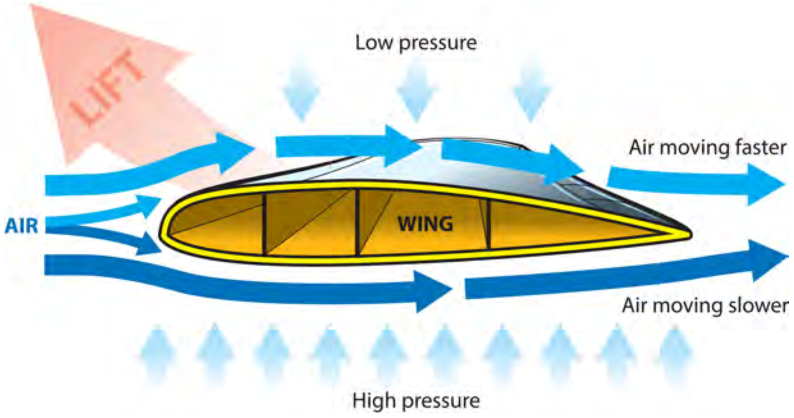

Figure 3.4. How lift is created via an aerofoil. (© NoPainNoGain/Shutterstock.com)

Attaching an aerofoil-shaped rear wing upside-down to a sports car works in the same way, but because it is upside down it creates a downwardly acting force—downforce—instead.

‘There are all sorts of different load cases that you have to analyse,’ says Peter, explaining that the first step is to build up a computerised model of the car then ‘mesh’ it. This means dividing the model up into very small elements that can each have mechanical properties applied to them. The program can then carry out partial differential equations for each of these tiny little elements, and so reveal what forces each section is subjected to. Figure 3.7 shows a forces and constraints plot.

The different colours on the resulting plots indicate the degree of displacement in millimetres under whichever load case is being studied. Results also included

Box 3.2. The *Elemental Rp1's* underfloor aerodynamics

Most of the downforce—which is perceptible from speeds of 60 mph and above—comes from the *Rp1*'s underfloor aerodynamics, which is unlike anything used before in a production car.

'We designed the *Rp1* from the onset to have underbody aerodynamics which is a more efficient way of achieving downforce than the more conventional addition of wings. It is basically similar to F1 and Le Mans design,' says Mark Fowler, Elemental's Aerodynamics and Body Engineering Manager.

'Our aero design was carried out in parallel with the mechanical design of the car which enabled us to maximise the underbody aerodynamics. This approach is unusual as road cars don't generally have underfloor bodywork—any aero work on most road cars is on drag reduction and minimizing lift rather than creating effective downforce. All our bodywork design is performance-driven; we gave as much attention to underbody design as upper body design. We have carried out sophisticated CFD [computational fluid dynamics] analysis to fully understand the aerodynamic performance in all dynamic positions of the car on track,' he continues.

The *Rp1's* underfloor bodywork comprises a front splitter, two front diffusers (one on either side), a main flat floor, and two rear diffusers. All these components control the airflow under the car (see figure 3.5), creating a pressure difference which results in downforce.

Figure 3.5. The air flow beneath the *Elemental Rp1*. (© Elemental Cars Ltd. Reproduced with permission.)

'The front splitter (leading edge of the floor) is a device used to feed air into the front diffusers which creates suction at the front of the car. So increasing the size of the splitter allows more air flow under the car and in turn will result in an increase in suction (downforce). The front and rear diffusers are basically rectangular in section. The front diffuser has an inlet behind the front splitter at the front of the car. The air then expands in its channel around the inside of the front wheels and exits upwards and away from the car behind the wheels [as shown in figure 3.5]. The rear diffuser inlets start mid-way under the floor and cause the air to expand over the remainder of the diffuser around the rear suspension wishbones before exiting upwards at the rear of the car,' explains Mark, adding that the different colours in figure 3.3 show the relative pressure of the air as it expands under the car. The colours range from blue representing low pressure to red which indicates high pressure. 'This shows where the downforce is acting as low pressure implies suction—i.e., the car is sucked to the ground.'

'Because the car has a considerable power:weight ratio, matching the cornering performance to the straight line speed requires finding enough grip to corner effectively,' continues Mark. 'If aerodynamic downforce (the downwards thrust created by the aerodynamics of the car) is high, it means that the car can corner faster because there is increased vertical force on the tyres and thus more grip, and as the car is pressed down towards the ground, its stability is increased. Our approach was to do high-level iterative CFD cases to prove this out without the need for manufacturing body panels and wind tunnel testing.'

'The *Rp1's* aero has been designed so that it is balanced—meaning that when on track, under hard braking and accelerating, or cornering conditions, it does not negatively impact on the downforce of the car, giving confidence to the driver and enabling faster lap times on the track. For most track day drivers it's all about car performance, which generally means lap times. Having good aerodynamics improves all aspects of car performance on track from cornering and braking to accelerating and top speed.'

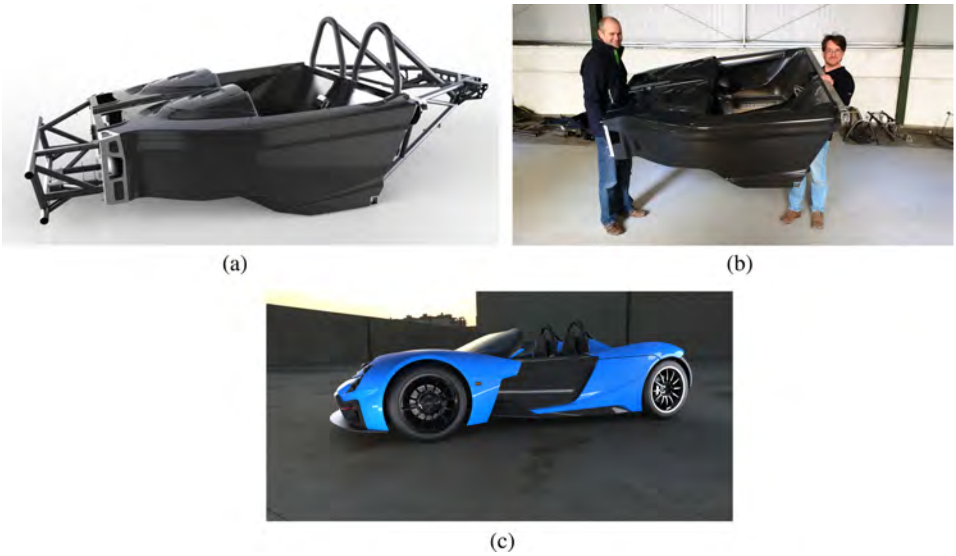

Figure 3.6. (a) The *Elemental Rp1*'s 68 kg tub; (b) Peter Kent (left) and John Begley (right) with the tub for the first production version of the *Rp1*; (c) side view of the *Rp1* showing the tub within the finished car. (© Elemental Cars Ltd. Reproduced with permission.)

a composite failure index, which enabled the team to see if greater amounts of material were needed in specific areas. 'There were just a few small areas where we had to increase tube diameters of materials or add more (carbon fibre) plys, but in general there were not many suggestions at all,' says Peter.

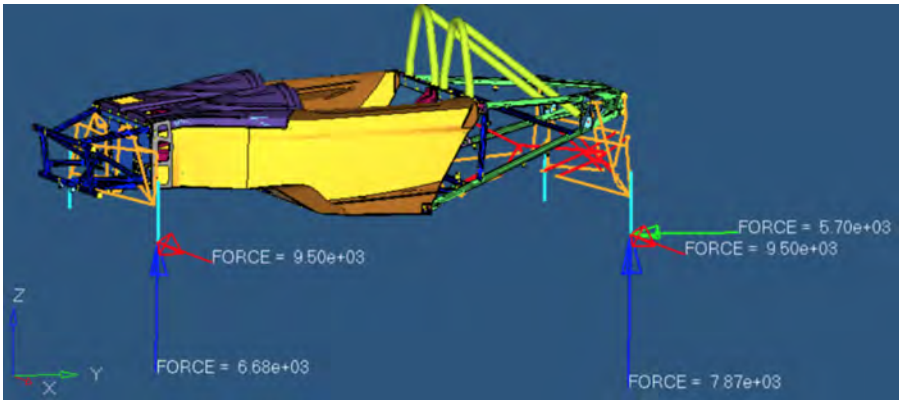

Figure 3.7. This forces and constraints plot shows one of the loadcases—specifically a worst case scenario of forces generated by acceleration and cornering—applied to the *Rp1*'s chassis. The forces shown are measured in newtons (N), and the greater the displacement the nearer the (false) colour tends towards the red. (© Elemental Cars Ltd. Reproduced with permission.)

Whilst computer modelling was essential for refining the aerodynamics, not all the modelling during the early design phases was done on computer. For instance, to ensure the design of the tub and the seating position were sound both from an ergonomics point of view, and for passing all the relevant legality tests, the team had a wooden mock-up of the tub made. They also created some rapid prototype parts.

'When we designed the windscreen we did a rapid prototype of the A pillar [which holds the windscreen in place] to make sure that when you sit in the car you get the vision you need. We also spent quite a bit of time developing our existing seat. We had a foam version of the new seat machined, then had a chiropractor sit in it so we could make sure that the next iteration was as comfortable as possible,' explains Peter, adding that they want people to be able to travel long distances—such as driving from the UK to Le Mans in France—in the car. Long-distance travel is also aided via 200 l of luggage space, a heater in the foot well, USB mobile phone charging facilities, and a 50 l fuel tank ('so you don't have to stop for fuel every 100 km') mounted as low down as possible to maintain the required weight distribution.

Materials selection was integral to how the car evolved. Carbon fibre, which is a composite material (see box 3.3), is used to make not only the tub, but also some of the structural cross-beams, and the dash panel—which incorporates an LED (see box 2.2) display, central control panel, and push-button starter system (see figure 3.8). Other materials including aluminium and ABS plastic (Acrylonitrile–Butadiene–Styrene) are also utilised. 'We only use carbon where we need to. The floor panel for example is a folded laser cut aluminium panel. The difference in price between an aluminium one and a composite one would be a lot and there's just no point [in using carbon fibre]. You don't get much weight saving, and structurally it is not a critical part of the vehicle as we have aluminium structural beams that do all the work with the load paths,' explains Peter.

Carbon fibre was, however, essential for the tub and some of the body panels in order to keep the *Rp1* as light as possible. For a given engine power, the lighter the

Box 3.3. Composites

The two or more materials that make up a composite provide a combination of properties not available from any single material. One of the most common examples of a composite is reinforced concrete, which is widely used by the building industry and has steel rods embedded in it to make the concrete much stronger when it is under tension.

Carbon fibre, which has a range of uses from prosthetic limbs to high performance cars, is made up from carbon fibres embedded in resin. 'Prepreg' is a dry, woven mat of carbon fibre pre-impregnated with activated resin. While most prepreg has carbon fibres running in different directions, very expensive prepreg with uni-directional fibres is used for highly specialised applications such as Formula 1 wishbones. These must withstand a high load path in one direction and so need all the fibres lined up in that direction in order to cope with the forces.

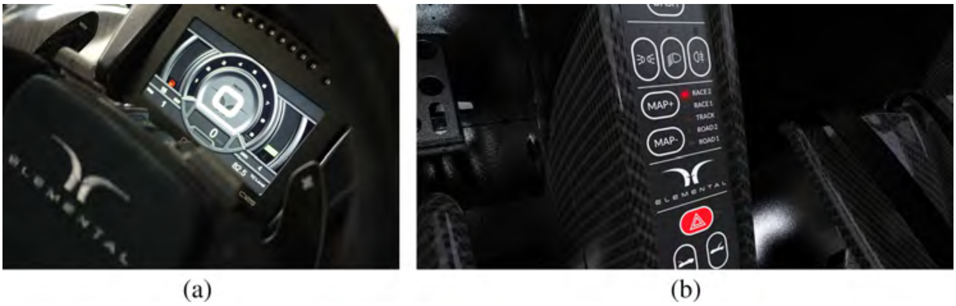

Figure 3.8. The carbon fibre dash panel incorporates (a) an LED display and (b) a central control panel. (© Elemental Cars Ltd. Reproduced with permission.)

weight of a car the faster and better handling it will be. Not only does the low weight of the *Rp1* enable high values of acceleration and speed, along with harder braking and tighter cornering, carbon fibre also gives the tub high torsional rigidity. 'Having the tub as torsionally stiff as possible means that your suspension then does exactly what it is supposed to do, and is not having to compensate for the chassis twisting,' says Peter.

The carbon fibre chosen by the Elemental team is a tried and tested 'prepreg' carbon fibre used in both the aerospace industry and motorsport. It consists of a woven mat of carbon fibres which is pre-impregnated with activated resin. In general, to make parts from prepreg, the carbon fibre mat is cut to shape and then laid carefully into a mould (see figure 3.9) with the weave laying at the angle determined by the FE (finite element) structural analysis. For example, if you have a high load path running from front to back along a component, the weave will need to be laid such that there are lots of fibres running in that direction as this enables the component to withstand the forces acting on it.

Layers are then built up to give the required thickness for the finished part, taking care to overlap them by a minimum of 10 mm to avoid creating weak points in the

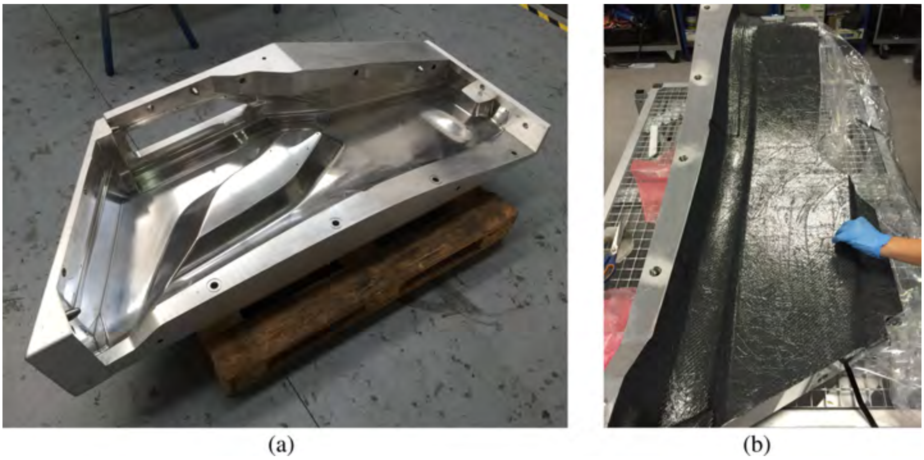
(a) (b)

Figure 3.9. (a) An aluminium side pod mould tool for the *Elemental Rp1*; (b) creating one of the carbon fibre tub components for the *Rp1*. (© Elemental Cars Ltd. Reproduced with permission.)

finished part. The mould surface is covered with 'breather cloth'—which allows any trapped air to be pushed out of the prepreg—then the mould is sealed inside a vacuum bag which is evacuated down to 1 bar (100 000 Pa) gauge pressure (which is the total pressure minus atmospheric pressure). Next it is placed into an oven or autoclave and pressurised up to 5 bar (500 000 Pa) to fully cure the resin. The *Rp1's* parts are cured in an autoclave at around 120 °C for 8 hours.

'When you design a composite component you need to give a lot of thought to what materials you are going to be using for the mould tools, as whichever material you choose will have a coefficient of thermal expansion [see box 3.4]. So you have to apply a scaling factor [related to that coefficient] to your mould tool or pattern design to ensure that you get the correct geometry for your carbon component at the end,' says Peter.

Most of the tooling for the *Rp1* is made from aluminium. To allow for expansion when heated in the oven, each aluminium mould tool needs to be made slightly smaller than the size required for the final carbon fibre component. For the *Elemental* team this meant machining the mould tools for the side pods approximately 3 mm smaller than the finished components needed to be, and using the same scaling factor to decrease the smaller mould tools proportionately.

'You have to take into consideration the temperature that you're going to be curing at. Generally it's either 100 °C or 120 °C. Once the resin crosslinks at that critical temperature, that's the geometry your part is going to have when you de-mould it from the mould tool. So for example if you want to cure at 100 °C you've got to select the correct scaling factor for that temperature and the particular grade of aluminium of your tool,' says Peter, who designed the *Rp1*'s mould tools to scale on a computer, then applied the scaling factor to account for the aluminium's thermal expansion.

Box 3.4. Thermal expansion

It is not just composites engineers who have to allow for solids expanding and contracting as their temperature alters. Architects and designers need to take expansion and contraction into account when they design any construction or object that will be exposed to a range of different temperatures. For instance, the arch of Sydney Harbour Bridge in Australia can become 18 cm higher on a really hot day, so this change must be allowed for.

For a reasonably wide range of temperatures, if a solid rod is heated the resulting increase in its length is proportional to the increase in temperature. This relationship is shown mathematically in the following equation

$$\frac{\Delta l}{l_0} = \alpha_l \Delta T \tag{3.1}$$

where l_0 is the length of the rod before it is heated, Δl is the change in its length, ΔT is the change in temperature and α_l is the 'linear coefficient of thermal expansion' for whatever material the rod is made from.

Table 3.1 shows the value of the linear expansion coefficient for a variety of solids. α_l increases as the temperature rises, and table 3.1 shows the room temperature values. When making any object from two or more different materials it is best to choose materials that have similar thermal expansion properties. This is because different rates and amounts of thermal expansion in the different materials will produce mechanical stresses that can cause damage to the object.

Table 3.1. The room temperature linear thermal expansion coefficient, α_l, for a selection of solids.

Material	Linear coefficient of thermal expansion, $\alpha_l \times 10^{-5}(\mathrm{K}^{-1})$
Polyethylene (low density)	18–40
Aluminium	2.39
Silver	1.89
Brass	1.8
Copper	1.7
Iron	1.17
Glass (pyrex)	0.32
Quartz	0.05

Equation 3.1 can be adapted to represent the changes in volume that occur when a solid expands by replacing the initial length and the change in length by initial volume and change in volume, respectively, and α_l by α_v which is the 'volume coefficient of thermal expansion'. For a lot of materials α_v has a different value along different directions in the material; such materials are described as being anisotropic.

The scaling factor does not just affect the overall dimensions of the finished part. It also impacts the positioning of holes for pins and bolts. ‘You have to be careful as you restructure your CAD model that your scaling is applied before you add on all your hole details,’ continues Peter.

Care must also be taken when removing each carbon fibre part from its mould. While the carbon does not shrink down, the aluminium mould tool ‘wants to go back to its original shape,’ explains Peter. ‘So you have to de-mould your part at about 80 °C. Otherwise you’ll be putting a huge amount of stress on your composite part as the aluminium mould tool cools down.’

While some of the *Rp1*’s components are made using these standard methods for creating carbon fibre parts, the tub is manufactured via a variation on these techniques developed by the Elemental team known as CarbonAl® technology. This patent-pending process reduces the manufacturing time for the tub, partly by enabling components that would normally consist of several glued-together sections to be made as one piece.

Another innovation for the *Rp1* is the use of a recently developed composite material. ‘We were approached by [industrial yarn manufacturers] Coats because they have developed a new thermoplastic material called Synergex. What’s special about Synergex is that you embroider your flat shape and you can get your fibre alignment whatever angle you want it,’ says Peter. This ‘tailored fibre placement’ enables the material to have fibres aligned at one angle in one section and at a different angle in another, as well as allowing thickness to be built up locally. (See box 3.5 for more on thermoplastics.)

So far, the team have used a version of Synergex consisting of a nylon-based carbon fibre for the wheel arch liners (see figure 3.12). While not safety critical, the *Rp1*’s wheel arch liners have to be fairly stiff as they help connect the two 100 l luggage pods to the rear structure of the car. They also need to be light to aid the car’s performance, and tough enough to withstand all the gravel and other debris that gets thrown up at them.

Synergex is made into component parts using a hot forming process called ShapeTex, which was developed by Shape Machining Ltd, based in Oxford in the UK. The parts are stamped out using matched female and male mould tools that are heated then brought together in a press. Once removed from the mould tool the part is CNC (computer numerical control) trimmed to finish it. The processing can be fully automated with a machine embroidering the component shape, and a robot taking the shape and placing it on the tool before lifting the part out after it has been pressed.

Choosing suitable materials is an important part of Peter’s job. ‘Every single thing you design you have to think: "what is the best material I can use for this?"’, he says. The conditions each part of the car needs to cope with are a key factor in that choice. ‘You’ve got to think what the part is going to be doing. Is it going to be battered by stones or gravel shot up by the wheel? How much of the aerodynamic load is going to be on that part? Our car creates such high levels of downforce that there’s a lot of extra load on the floor of the diffuser for example. So you’ve got to make sure that

Box 3.5. Thermoplastics

Artificial polymers are commonly called ‘plastics’, and they have many different applications from waterproof garments to drinks packaging. Polymers that become soft when they are heated, and only harden up if they cool down are known as thermoplastics. Widely used thermoplastics include PVC, polystyrene and PTFE. Most types of thermoplastic are reasonably soft and flexible at room temperature, but become softer and more pliable if they get hotter. Thermoplastics behave like this because of their structure.

All polymers are solid materials made from very large molecules, which are themselves composed of many smaller, identical building blocks of molecules known as monomers. A 2D diagram of the polymer polyethylene (which is commonly known as polythene) together with its monomer ethylene is shown in figure 3.10.

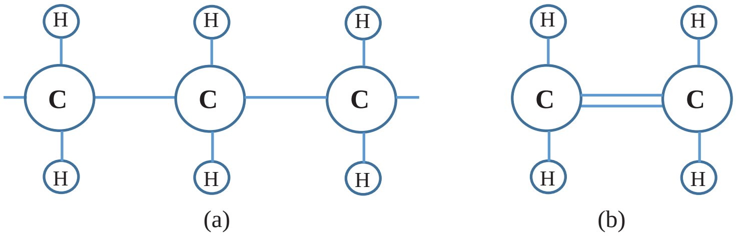

Figure 3.10. (a) A 2D representation of polyethylene, which is more generally called polythene. Each ‘C’ represents a carbon atom, while ‘H’ depicts hydrogen. (b) Polythene’s monomer ethylene. Polymers made up from carbon and hydrogen are known as hydrocarbons.

However there are three main ways—linear, branched and cross-linked—that these long chains can be arranged (see figure 3.11), each of which creates different polymer properties.

Thermoplastics consist of either linear or branched polymer chains. The types of thermoplastics used for clothing are made up from linear polymer chains (see figure 3.11(a)). These chains can slide past each other easily because they are randomly arranged like noodles in a bowl, and are held together by either van der Waals bonds or hydrogen bonds which are both relatively weak types of atomic bonds. The ability for the chains to move readily is what gives these thermoplastics their flexibility.

By contrast the side branches of branched polymer chains (see figure 3.11(b)) are covalently bonded—in a covalent bond a pair of electrons is shared between two atoms—which is a much stronger type of bonding. This makes it harder for the chains to move past one another, and so produces a stiffer, stronger polymer.

The stiffest polymers consist of cross-linked polymer chains (see figure 3.11(c)). These chains are unable to slide past one another at all as their cross-links are made up of covalently bonded atoms, and so the chains are held together with strong covalent bonds. Thermosetting plastics, also known as thermosets, are cross-linked polymers. Unlike thermoplastics, themosets cannot be softened and reshaped so cannot be recycled.

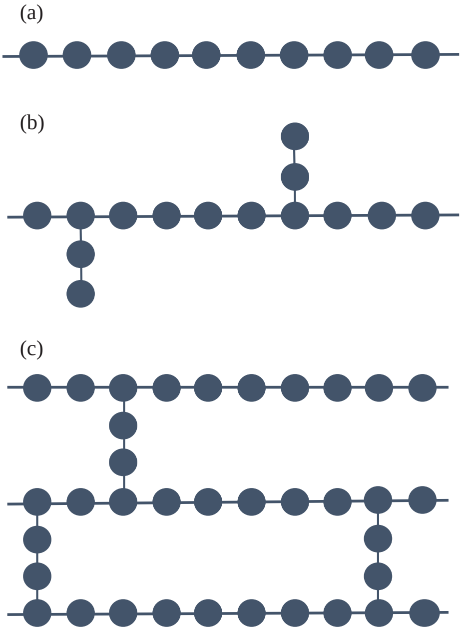

Figure 3.11. (a) a linear polymer chain; (b) a branched polymer chain; (c) a cross-linked polymer chain.

While materials like polythene and PVC are artificially created, many natural polymers also exist including cotton, wool, leather, and rubber.

diffuser is capable of withstanding all of that load, and will stay that way for 10 or 15 years,' explains Peter.

As well as carefully designing and selecting materials for each part, the Elemental team needed to create detailed 'build instructions' for the assembly of the car before it went into production. These instructions include a collection of technical drawings that give a step-by-step assembly guide for the car's tub, which pieces together like a giant 3D jigsaw puzzle.

'We defined how much glue coverage there should be because it is a bonded assembly and it is critical that you have enough adhesive and surface preparation for your adhesive. With aluminium you have got to bond it fairly quickly after preparing the surface because the surface will oxidise, and if the surface oxidises you get a weak layer in between the aluminium and adhesive. You can lose quite a large percentage of the structural integrity of the joint. It's similar to how avalanches work: you have a layer of snow on a warm day then get snowfall on top of that which results in a very low friction coefficient between the two layers,' says Peter, adding that they use a very simple aluminium jig when bonding the tub together.

Several parts of the car require their own sub-assemblies. 'One is the floor, and that is built up separately. We've developed our own sandwich panel construction

Figure 3.12. The *Elemental Rp1*'s wheel arch liners are made from Coats Synergex composite thermoplastic. (© Elemental Cars Ltd. Reproduced with permission.)

using aluminium and foam, and aluminium inserts. We then marry that with our carbon fibre components', explains Peter.

While the tubs and carbon composite bodywork for the production vehicles are made and assembled by Optimal Structural Solutions in Portugal, the final assembly stages for each car take place at Elemental in the UK. The ease with which the cars can now be put together is, says Peter, thanks to both the comprehensive set of assembly instructions and the attention to design.

'We've gone through every scenario: Can you get a spanner in to do that bolt up properly? Can you get that rivet gun into that place to rivet that bit together? You don't want to assemble the car and then realise you can't actually put it together. You have to go through so many different scenarios: Which way should we have the dampers up if you want to be able to adjust them? They all have knock-on effects onto everything else. So you have to design a lot of the car before you can start making components,' he says. 'When we design something, the devil is always in the detail. You can get 80% of your design done in 20% of the time. The final 20% to really get everything designed properly takes the time, and that's what we've tried to do with this car.'

3.3 Materials used in supercars

The Swedish supercar manufacturer Koenigsegg has been producing cars for over 20 years, having been founded by Christian von Koenigsegg in 1994 with the aim of creating the 'perfect supercar'. Bespoke manufacturing techniques, and a careful choice of modern materials are integral to their cars, as Steven Wade, Manager, Communications and PR for Koenigsegg Automotive explains.

'A visit to the Koenigsegg factory is unlike a visit anywhere else. The most notable difference between our factory and nearly every other car factory in the world is that we have no robots. Everything is done by hand—whether it be making carbon fibre parts for our vehicles or machining engine parts. Our extensive use of carbon fibre makes us a very labour-intensive company,' he says, adding that 'nearly every single component in a Koenigsegg car is designed for that car by our crew of designers and engineers.'

'Koenigsegg is a pioneer in the use of carbon fibre for road cars. Our chassis tub is made from carbon fibre with an aluminium honeycomb sandwich construction. The entire tub, including the aluminium fuel tank housed within, weighs just 72 kg yet it is the core of an industry leading torsional rigidity figure of 65 000 Nm per degree of twist. Aside from the tub, we use carbon fibre extensively throughout the car. Every exterior and interior panel is made from carbon fibre. Our steering wheel and seats are made from carbon fibre. Engine components such as the cam covers, airbox, and intake plenum are all made in-house from carbon fibre,' continues Steven, adding that the primary advantage of using so much carbon fibre is weight reduction.

Weight is crucial for sports car performance, as Steven explains. 'You can add massive power to nearly any car but the key to getting around a track quickly is for that car to be light. Lightness means faster acceleration, shorter braking distances, less inertia [see box 3.6] when you enter corners and much greater control.'

As well as being extremely light, carbon fibre is strong, and can be shaped into nearly any form. 'Our customers also love the look of carbon fibre. Many customers choose a clear coating over the carbon fibre exterior instead of paint, or a combination of clear carbon and painted stripes or sections,' says Steven.

'We make our own carbon fibre wheels and were the first (and still the only) OEM [original equipment manufacturer] to do so,' he continues. Koenigsegg's latest model, the *Regera* (see figure 3.13)—a hybrid with a combination of three electric motors and a V8 internal combustion engine—has 'Tresex' hollow-core carbon fibre wheels, which each contain 750 individual pieces of carbon fibre and take a craftsperson 10 days to make.

'Our Tresex carbon fibre wheels are around 40% lighter than our regular lightweight alloy wheels (which are already extremely light by industry standards). They are a six-spoke wheel, with hollow cores inside the spokes. The wheels have a concentration of carbon fibre around the hub, which is the place that receives the most stress under load. The spokes themselves are comparatively thin and hollow.

Box 3.6. Inertia

Inertia is a property of matter that makes it resist any changes to the motion it may have, or to its state of rest. So if a body is not moving it will remain stationary unless a force acts on it and causes it to move. Similarly if a body is moving, this motion will not be altered—so the speed and direction will remain the same— unless a force acts on the body. The larger the inertia of a body, the greater the force required to either alter its existing motion, or get it moving if it is at rest.

Inertia can therefore be thought of as a body's reluctance to being moved, or having its existing motion altered. The greater the mass of a body, the larger its inertia will be. So a body's mass can be considered a measure of its inertia.

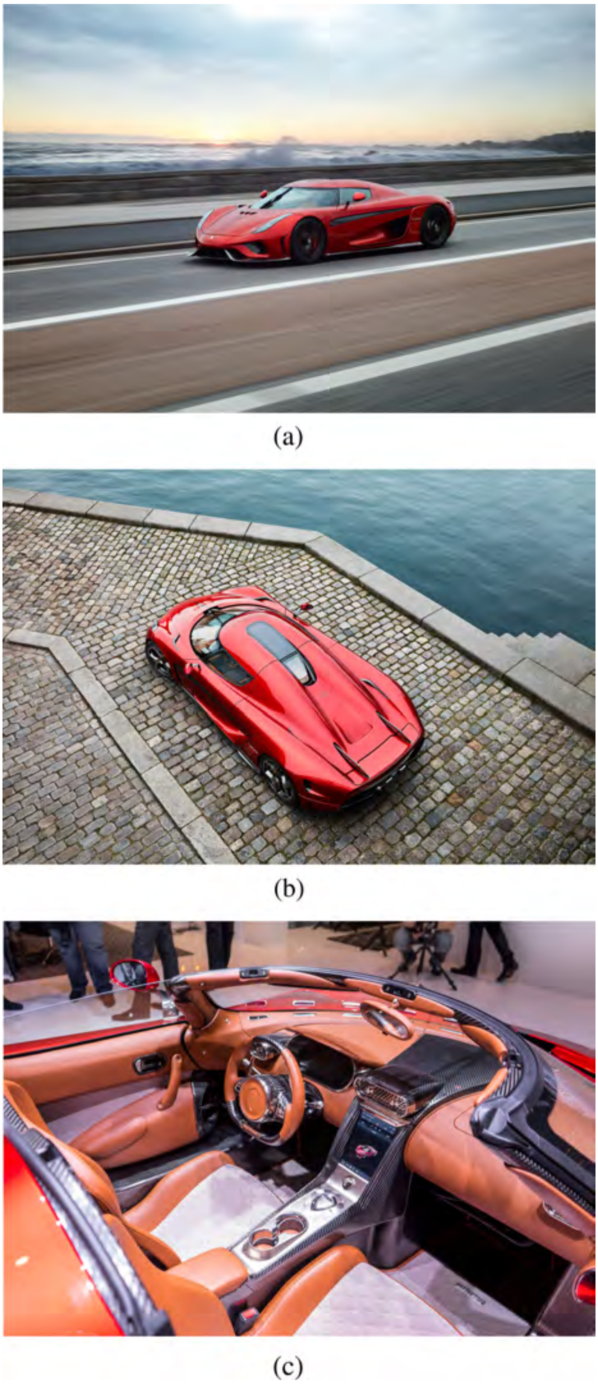

Figure 3.13. Koenigsegg's latest model, the *Regera*. (a) the 'Tresex' hollow-core carbon fibre wheels each contain 750 individual pieces of carbon fibre (Photographer: Martin Juul); (b) every exterior and interior panel is made from carbon fibre (Photographer: Martin Juul); as are (c) the steering wheel and seats (Photographer: Lisa Johansson). (All images © Koenigsegg Automotive AB. Reproduced with permission.)

Box 3.7. Alloys

Pure metals are too soft for certain applications, and are not particularly easy to machine. However, if two or more metals, and sometimes also non-metallic elements, are mixed together, an alloy is formed that has a combination of the properties of its constituents. Alloys can therefore be created with properties tailored for specific uses. For example, stainless steel, which must not rust, contains chromium to improve the corrosion resistance of the steel, which is an alloy itself predominantly made from iron and the non-metallic element carbon. Other commonly used alloys include brass which is mainly made up from copper and zinc, and bronze whose main constituents are copper and tin. While many alloys are created artificially for specific applications, alloys do exist in nature. For instance iron–nickel alloys can be found in some types of meteorite.


(a) (b)

Figure 3.14. Renderings of the (a) exterior and (b) interior of the *Koenigsegg One:*1. (© Koenigsegg Automotive AB. Reproduced with permission.)

The wheels are 99.9% carbon fibre, which gives them supreme strength and lightness. The 0.01% that's not carbon fibre is the valve stem that lets the air into the tyre.'

'Our segment in the automotive industry is extreme high performance. We rely on extreme technology to gain any and every advantage possible. Lighter wheels mean faster acceleration off the line as well as minimal rolling inertia, which is critical both when braking and when cornering at speed,' says Steven.

Carbon fibre is not, however, the only lightweight modern material used in Koenigsegg cars. The exhaust headers, for instance, are made from the alloy Inconel 'because it is extremely light and has great heat transfer properties. We use titanium for other exhaust components, again because of its extreme lightness,' explains Steven. (See box 3.7 for more on alloys.)

In addition, some of the machined parts are made from aircraft-grade aluminium chosen for both its strength and lightness, while a relatively new fibre called Dyneema—which improves the impact resistance of carbon fibre—provides additional chassis crash protection. Koenigsegg also use gold in sections of their engine bay both for aesthetic reasons and to provide good heat reflection.

The *Regera* goes from 0–400 kph (248.5 mph) in under 20 s, and produces 1500 h.p. (See box 4.1 for more on horsepower.) 'Cars with so much power also need a lot of stopping power, which is why we used the most advanced carbon-ceramic braking system available. We also use optic-fibre wiring in places to improve the speed and reliability of data transfer,' says Steven.

The modern materials chosen have been the cornerstone of Koenigsegg's success, as Steven explains. 'We could certainly build supercars without these materials but the cars wouldn't be anywhere near as competitive. Our extensive use of carbon fibre and other weight-reduction research allowed us, in 2014, to develop and build the world's first production vehicle with a 1:1 power-to-weight ratio. The *Koenigsegg One:*1 [see figure 3.14] set multiple speed and acceleration records at race tracks around the world.'

Further Reading

Holgate S A 2010 *Understanding Solid State Physics* (CRC Press) ISBN: 978-0-7503-0972-1

Holgate S A 2017 Driving materials forward *Mater. World* **25**(7) 34–7

Weblinks (live as at June 2018)

Elemental Cars website
http://elementalcars.co.uk/
Official YouTube channel of Elemental Motor Company Ltd
https://www.youtube.com/user/ElementalCars
Carbon Fiber Education Center from materials company Zoltek
http://zoltek.com/carbon-fiber/what-is-carbon-fiber/
Koenigsegg website
https://www.koenigsegg.com/
Official YouTube channel of Koenigsegg
https://www.youtube.com/user/KoenigseggSweden

IOP Concise Physics

Outside the Research Lab
Volume 2: Physics in vintage and modern transport
Sharon Ann Holgate

Chapter 4

Hitting the road—physics and technology in vintage buses

4.1 Introduction

When we travel by vintage or modern buses, we probably don’t give much thought to the physics and technology used to keep those vehicles on the road. However both are essential for not only creating and maintaining the bus fleets of today, but also enabling the faithful restoration of buses from years gone by.

In this chapter we will first hear what modern physics and technology goes into restoring vintage horse-drawn buses, thanks to my friend Tony Drewitt, who has provided horse-drawn vehicles for events, and for TV and film productions, for over 30 years. Tony—with whom I co-presented science and magic shows in 2005 and 2006 as he is also a professional magician—restores his fleet of vehicles partly himself and also with the help of other experts. In addition, Tony reveals how physics and technology impacted on horse bus development in Britain in the 19th century.

Finally, thanks to Ron Medaglia, Executive Director of the Pacific Bus Museum in the United States, we will learn what technologies made the Greyhound Scenicruisers the pride of the intercity bus operator Greyhound Lines Inc.’s fleet. We will also hear how he and his follow volunteers at the Pacific Bus Museum are currently restoring a 1955 Greyhound Scenicruiser number 8005.

4.2 Horse-drawn buses

For carriage master Tony Drewitt new technology has played a pivotal role in returning his latest restoration project, a 1911 horse bus, back to the road. The story began for Tony thanks to the Internet.

‘In 2011, the head horseman Chris Thompson from Beamish Museum [an open-air museum of rural life in County Durham in the UK] who had looked after three horse buses got in touch with my son Christopher to say there was a horse bus for

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sale on eBay. I thought Christopher was joking when he phoned to tell me,' recalls Tony, who soon took it seriously once he saw the photographs on eBay and realised this was potentially a rare find.

'I emailed the seller immediately, and then you couldn't see me for dust. I got in my car and went straight down to Battle [near Hastings] to meet him and look at the bus. In a stroke of luck it had just expired on eBay as there had been no offers on it.'

Tony began checking the derelict bus (see figure 4.1(a)) carefully to be certain that it was what it appeared to be at first sight. 'It was at the back of a farm, still glazed and painted yellow. But it been dissected at some point and had a door added at the rear and the staircase taken off. So it had been modified for some use on the farm. But it still had its carriage license stamp.'

Finding the carriage license stamp was the first step in unravelling the history of the vehicle, as Tony explains. 'In the 19th century, it was found necessary to regulate and control public service and HGV vehicles to ensure safe operation. They were licensed annually (buses were given a carriage licence stamp), and still to this day are licensed based on regulations that existed in the late Victorian period. In some ways health and safety was abysmal then, but public service vehicles were actually controlled quite heavily. One of the key things about this vehicle is that its carriage license stamp was for June 1911, which is very, very late for a horse bus to be operating in London. The last London General Omnibus Company horse bus pulled out of its stables in October 1911.'

Amazed to discover this bus had been in use a year after the mechanisation of most London buses, Tony made further finds when he looked inside the derelict vehicle. (See figure/video 4.2.)

'The destination boards that used to clip on the outside of the bus had miraculously survived. They had been used as pot plant shelves inside the vehicle

(a) (b)

Figure 4.1. Horse bus 'before' and 'after'. (a) The derelict horse bus being collected from its previous owner in Battle by Tony Drewitt in 2011; (b) the same bus in its fully restored condition being prepared for the Lord Mayor's Procession in London in November 2017. Vesper, the horse seen on the right, is a 16 hands (1.6 m) high 10-year-old Percheron cross Friesian mare. (© Tony Drewitt. Reproduced with permission.)

Figure/Video 4.2. Christopher and Tony Drewitt identifying the old derelict horse bus. The fare board, the destination boards, and the 1911 carriage stamp had survived. (© Tony Drewitt. Reproduced with permission.) Video available at https://doi.org/10.1088/978-1-64327-270-2.

remains. We also found the fare board. So we knew the exact route the bus used to take because of its fare board and its destination boards, and we had the 1911 carriage stamp. We went and did some homework in the records at the London Transport Museum, and are pretty sure that this vehicle was one of the very last horse-powered buses to ever go to the Mansion House in the City of London,' explains Tony, adding that because the Mansion House is the home of the Lord Mayor of London and the bus has this unique history he was asked to appear with it in the 2017 procession of the Lord Mayor's Show. (Figure 4.1(b) shows the bus in its fully restored condition being prepared for the Lord Mayor's Procession in London in November 2017.)

Modern technology did not just help Tony find the derelict vehicle. It was also important during the six-year restoration of the bus, which is the second horse bus in Tony's fleet of historic vehicles. Figure 1.4 shows the first horse bus that Tony restored, between 1973 and 1979. This bus dates from 1897, and was also originally used in London and has appeared in the procession of the Lord Mayor's Show, debuting in 1986. Since then it has appeared over twenty times representing a variety of associations and companies via bespoke advertising boards on its side. As with his latest restoration project, restoring the 1897 horse bus necessitated pulling a range of outside expertise together. Both buses required many different specialist components including springs for the suspension, lamps, a bell, handrails, and cushions. 'You have to source all those things as the project moves along. So we found a spring smith, a wheelwright [see figure 4.3], and an upholsterer, and sourced the glass, wicks, and reservoirs for the lamps as well as someone to assemble them,' says Tony.

Bringing vintage vehicles back to roadworthiness is a different process compared with creating new horse-drawn vehicles. 'If we make a new horse-drawn vehicle, it


(a) (b)

Figure 4.3. During restoration of Tony Drewitt's 1911 Garden-seat horse bus. (a) From left to right, Christopher Drewitt (Tony's son), wheelwright Edward Crouch owner of Croford Coachbuilders, and Tony Drewitt in front of the stripped down wooden bus frame. Edward, who is a Liveryman of The Worshipful Company of Wheelwrights, masterminded the restoration and together with his craftsmen stripped the body and wheels down, and made all the necessary repairs using the correct type of timber and working to some original plans of the horse bus construction; (b) side view of the shell of the bus with Tony and Edward discussing the project in the background. (© John Stiles. Reproduced with permission.)

must conform to [the UK's] Ministry of Transport regulations. We need LED lighting [see box 2.2], disc brakes, a sub frame or metal chassis, and toughened kite marked glass. But restored vehicles are different. They can have all original parts, or copies, or repaired parts provided they work. The vehicle does not have to have anything added if it was not fitted with it when it was made. As an example, early motor cars did not require seat belts therefore they are not obligatory [in the UK] on a vehicle made prior to the date the law was introduced,' explains Tony, who has provided horse-drawn vehicles for weddings, special events, TV, and feature films including British comedy film *The Missionary* (1982). The forging techniques used to create horse-drawn vehicles today are modern, as are the materials used for the bodywork, which are often lightweight materials commonly used in aircraft. 'For example, some modern horse-drawn coaches have aluminium wheels,' continues Tony.

While restoring both horse buses Tony found he relied heavily on modern technology, and thought about the advantages it gave him compared with the people working on horse buses when they were in service. 'I often wonder: how on Earth did they cope in the 1830s in a cold mid-winter with oil lamps and just their own muscle power? The technology we have today is helping us fabricate something that looks exactly the same as it did 100 years ago, but is easier to create. Electricity has improved everything. For instance, in the nineteenth century when you put your saw on some wood that was marked up by a pencil, the candle light would cast a shadow and the line [for sawing along] would appear to move. With electric lighting all those sorts of problems disappear,' he explains.

'Gas torches used today by blacksmiths can be used *in situ* rather than having to heat them up away from the area where you're working and keep bringing them across. So artificial light and power tools rather than flickering oil lamps and hand tools, as well as modern paints which dry much faster, have made a big difference to the sorts of work that is required to maintain and restore horse-drawn buses,' continues Tony.

There was however some help from the past with Tony's latest horse bus restoration in the form of a set of original plans, and from advice that Tony obtained back in 1969 when he was in the UK Police Force and working on horse-drawn vehicles as a hobby.

'When I was 19, I met a restorer called Eric Goodey who was restoring a Garden-seat horse bus from the London Road Car Company. He wasn't an ordinary person. He was like a Victorian living in modern times. It felt like talking to someone who had just stepped out of one of Charles Dicken's books. Anything to do with horse buses I was getting from a guy who had associated with people from that period. He went and found people who had worked on the horse buses in the 19th century, and immersed himself in the past. So he, and the people he knew, were very clued up on this technology.'

'There is nothing better than finding out from somebody who actually knows first-hand about the subject. So I became a piece of blotting paper and absorbed the information very quickly from Eric and his associates. I was very lucky because once you break that chain of learning that technology is lost for all time. You can never re-gain it. Fortunately my son Christopher is deeply immersed in this technology too, and has a full-time job in carriage restoration. He has learnt from people he works with whose technical knowledge has also been passed down through several generations,' says Tony, who studied criminal law at college before going into the Police force. Having enjoyed woodwork, technical drawing, and metalwork at school and finding vintage vehicle restoration work 'much more rewarding' he soon left the Police and set up in business as a carriage master, turning his hobby into a full-time job and learning more about the history of the horse-drawn omnibus.

Horse buses had first been introduced during the industrial revolution. 'In 1825 you had the opening of the Liverpool and Manchester Railway, and people were beginning to travel rather than living and working where they were born. The first regular horse omnibus service in London was introduced in 1829 by [English coach builder] George Shillibeer [1797–1866] who had seen horse buses working in Paris. He realised that as the industrial revolution expanded, the need for carrying passengers [in Britain] was increasing,' says Tony, adding that the first 'Shillibeer' design had to have three horses abreast to power it. This bus design was quickly copied, and by the middle of the 19th century many private companies were operating horse buses in Britain's towns and cities.

Not surprisingly, horse buses had to be built to suit the horse. 'The positioning of the wheels, and other aspects of the construction of the vehicles—such as the distance between the splinter bar [the crossbar that the horses are attached to via their harness] and the shoulder of the horse—was all designed around a 17 hand (1.7 m) draught horse,' explains Tony. (See box 4.1 for more on horse power.)

Between the introduction of horse buses and the last horse buses built in 1911 'there were significant changes to the technology,' continues Tony. 'Most inner-city and town conveyances were restricted to a single horse, or a pair of horses—which

Box 4.1. Horsepower

In general, power is the rate at which work is done or energy is transferred from one system to another. The power of a car's petrol engine for instance is the rate at which the engine converts the chemical energy from the fuel (in this case petrol) into mechanical energy that moves the car.

Although it is not part of the SI system of units, horsepower, the imperial unit of power, is still commonly used when describing the output of engines. It has the symbol h.p. and 1 h.p. is equal to 745.7 W. Horsepower was first used as a unit by the British inventor James Watt (1736–1819). While the SI unit of power the watt (W) is named after James Watt and is defined as a power of 1 J s^{-1}, horsepower is defined as 550 foot-pound force per second, which is 33 000 foot-pounds per minute.

A value of 1 horsepower (1 h.p.) is approximately the rate at which a breed of heavy horse known as a Clydesdale can do work. Thanks to experiments in the late 18th century it was found that an average heavy horse harnessed up to a 330 pound weight could pull that weight up a shaft at a rate of 100 feet per minute. Describing the outputs of engines in terms of horsepower therefore gives a guide as to how much more powerful that engine is than a heavy horse.

A variant on horsepower, brake horsepower (b.h.p.) is equivalent to the theoretical horsepower developed by an engine minus the power lost by working against friction in the engine. So b.h.p. gives a measure of the h.p. at the engine's output. Table 4.1 compares the horsepower ratings for some of the different transport featured in this book.

Table 4.1. Comparative horsepower ratings for some of the different transport featured in this book.

Vehicle/Locomotive	Horsepower (h.p.)
Horse bus pulled by two Clydesdale horses	2
Greyhound Scenicruiser 8005	318
Elemental Rp1	320
Class 08 and 09 diesel shunting locomotives	350 or 400
Koenigsegg Regera	1500

most buses had, or a team of four or six horses on a coach. Most of the improvements in bus technology were aimed at pair horse work, which was the optimum combination for ease of driving and manoeuvrability, although a third horse known as a 'trace horse' was often harnessed on to assist when negotiating particularly hilly roads.'

'The London bus companies began [making improvements] by looking at the animal itself—assessing the efficiency of the horse,' says Tony. 'They asked: what can we do to get round London's narrow streets and low bridges with maximum efficiency? So the technology of horsepower affected the breeding of horses. You needed maximum motive power from the pair and by looking at a 17 hand horse and where its collar fits, you ask: what is that animal able to convert into power?

Progressive breeding—by out-of-town breeders who supplied the bus companies with horses—led to the most efficient horses for doing that job.'

Whilst powerful, the horses had to be changed over every 7 or 8 miles, so all the infrastructure required to run a bus service had to be built with horses in mind. As Tony explains, this infrastructure had to be totally altered with mechanisation. 'A vast amount of space was occupied with out of town pasture, stables and infirmary premises. This, along with the harness rooms and changing horses, was made redundant as was the huge amount of manpower for animal management and cleaning, and for repairing harness. Also, the storage facilities for feed, bedding, and manure were no longer needed.' Similarly the current move towards electric powered buses is necessitating different infrastructure to that required for diesel-powered buses (see figure 4.4).

'The horsepower had to work alongside what the coach builder could create. People were trying to reduce the weight of vehicles [to increase their efficiency] by using different woods. Also, UK horse bus design was being influenced from [horse-drawn vehicles in use in] France and the United States. For example a farm cart in England will almost inevitably work in a muddy field, so they would increase the width of the wheel and have big hubs to spread the load so that the wheels were less


(a) (b)

Figure 4.4. Siemens charging technology for electric buses. (a) This picture, taken in June 2015, shows a fully electrified bus (e-bus) departing from the indoor station at Chalmers Campus Johanneberg. This is part of the then new electric bus route 55 between Lindholmen and Johanneberg in Gothenburg, Sweden. Siemens, together with the communal energy supplier Göteborg Energi, installed two high-power charging stations, one at each end of the route, and supplied the complete charging system. The vehicles are equipped with battery packs that are charged with renewable electricity. This was the first time a Siemens charging station was installed indoors. Instead of being housed at the top of a mast system, the pantograph is located on the ceiling of the building. (Photographer: Daniel Stiller/BILDBYRÅN. Courtesy of Siemens. www.siemens.com/press); (b) this charging technology from Siemens, shown here during its world debut in Hamburg, Germany in August 2016, enables e-buses from different bus manufactures to charge at the same charging stations. Siemens was the first supplier worldwide to provide a charging infrastructure for e-buses that ensures interoperability for vehicles from different manufacturers. The charging process is as per open international standards IEC 61851 and ISO 15118 that are the basis for e-bus charging systems. The open standards enable vehicles from different manufacturers to use the same charging system. This solution allows operators to select their e-buses independently of the charging infrastructure and ensures their interoperability. (Photographer: Axel Schmidt. Courtesy of Siemens. www.siemens.com/press).

likely to sink into mud. Buses are the complete opposite, running on tar, wood block, or cobblestone roads where the need for wide wheels no longer existed because roads were perfectly suitable for a much more slender wheel. The Americans had some wonderful vehicles in the Wild West running on relatively un-rutted roads because of the different climate. So in the UK we looked at their "surreys" [a four-wheeled lightweight carriage with two separate seats] and "buck-boards" (which had lightweight, large diameter wheels and broad axles with a long wheel base giving stability and elegance) and began adopting the American idea of slender wheels [see figure 4.5].'

Figure 4.5. An American horse-drawn buggy. Designs like this influenced the wheel design for horse buses in the UK. (© DESmith Photography/Shutterstock.com.)

'A simple wheel construction is known as a mortice and tenon construction', continues Tony. 'The mortice is the slot and the tenon is the bit that goes into it. So it is a carpenter's joint. The Amercians had reduced the size of the wheel hub by using a drop forged metal collar, which was called a Warner band [named after their inventor, a wheelwright from New Jersey]. This had pre-set mortices in it so the spokes go into it and give greater strength, but keep the wheel much lighter. So they pre-made in metal a band with the mortice for the spokes drop-forged by a blacksmith.'

'A lot of innovations were coming in [in the UK] to achieve a lighter vehicle but keep it as strong as possible. By the advent of the industrial revolution the construction of these vehicles was changing rapidly because they could make them much finer,' says Tony, adding that 'the wheels were always a very important part of the construction of the vehicle because they were the fundamental moving parts.'

The 1851 Great Exhibition in the Crystal Palace in Hyde Park produced the next major turning point in the development of the horse bus. With so many visitors descending on the capital, many arriving by train, there was a need for much greater passenger capacity in the buses while still using just a pair of horses to pull them.

'Between 1829 and 1851 buses had been single decker with a door at the back. These were comfortable and slender, and reasonably efficient. But the idea for the double-decker bus was born out of the need to convey large numbers of passengers to and from the Great Exhibition,' says Tony, adding that many agile passengers got impatient and climbed onto the roof luggage racks to speed their arrival at the Great Exhibition. 'This proved that the fragile looking construction could actually work well carrying roof passengers.'

This was just as well, since the capacity of the contemporary horse buses was also being outstripped by mass passenger footfall created by the rapidly developing railway network. Commuters and visitors were being brought into London in ever increasing numbers by trains operated by private rail companies who each had their own rail terminus in the capital. To attract customers to horse buses, which often had a sixpence fare—which was beyond the reach of many—bus operators made sure that both drivers and horse harness looked smart, alongside bringing in technical innovations says Tony. 'The Metropolitan Railway (Met) for example had its own fleet of horse buses, with drivers wearing the Met railway uniforms.'

The first double decker horse bus design was known as the 'Knifeboard' bus, and had been very carefully thought through explains Tony. 'Twenty six passengers was the optimum number of passengers that a bus could carry because of the weight. If you went above twenty six you would require more horsepower on most routes. Initially the Knifeboard bus had an iron rung staircase on the back to access the roof deck and you sat back-to-back on an upholstered bench. So it had progressed from sitting in the luggage rack at the Great Exhibition to this seating arrangement, which looked like a knifeboard for cleaning knives in the kitchen. This design replaced the 'Shillibeers' and became very popular.'

By the early 1880s, many different types of bus construction had been experimented with. 'There was a competition in the 1870s offering a reward of £100 to an apprentice coach builder who could design an improved horse bus. The winner's idea was never actually adopted, but the ideas that came forward were amalgamated to produce the 'Garden-seat' bus in 1888,' says Tony. This design—with its garden-

Figure 4.6. End view of Tony Drewitt's 1911 Garden-seat horse bus during restoration, showing the curved roof and upright posts. (© John Stiles. Reproduced with permission.)

bench-style double seats facing in the direction of travel on either side of a central gangway on the upper deck—was to become the blueprint for the last of the horse buses, and both of Tony's horse buses are of this design.

One of the innovations adopted in the Garden-seat bus was to lower the centre of gravity and so make the vehicle more stable when carrying people on the top. This necessitated dropping the front of the inner carriage of the main bus body down lower. 'The early double decker horse buses were putting people too high and operators wanted to bring that height down. So you had what was called a 'sunken fore-carriage' which allowed the well of the interior of the bus (where you sit) to be as low as possible,' explains Tony, adding that the slope of the inner carriage increased as you got to the rear of the bus. While this meant less leg room for passengers travelling at the front of the inside deck, it had the advantage of enabling an easy step up into the bus via the platform at the back.

Dropping the centre of gravity also required the front wheels to be reduced in size while the back wheel size was increased. 'The traditional American-style wheels were also abandoned in favour of a slightly bigger 'English pattern' wheel where they staggered the spokes like a bicycle wheel to give it maximum strength,' says Tony. In addition, in order to weave in and out of traffic the back and front wheels were moved nearer together to shorten the wheelbase and so improve the manoeuvrability of these 3 tonne vehicles.

'If you look at the images [see figure 4.6] of my recent restoration project, they show the design of the [Garden-seat] bus frame, which is almost like a barrel and a

Box 4.2. Stress

In physics and materials science, stress is defined as the force per unit cross-sectional area acting on a material object. When stress is applied to a solid material, it causes the material to deform and so change shape. The SI derived unit for stress is the pascal (Pa), which is named after the French mathematician and physicist Blaise Pascal (1623–1662). 1 Pa is equivalent to 1 Nm^{-2} (one newton per square metre), as can be seen from the following simple equation for stress

$$\sigma = \frac{F}{A} \tag{4.1}$$

where σ is the stress in pascals, F is the force in newtons and A is the cross-sectional area in metres squared of the solid material that the force is acting on.

There are three different types of stress: tensile stress, compressive stress, and shear stress. Each type causes a different change in shape, as shown in figure 4.7. While tensile stress pulls on an object and stretches it, compressive stress squeezes an object and squashes it, and shear stress creates a distortion.

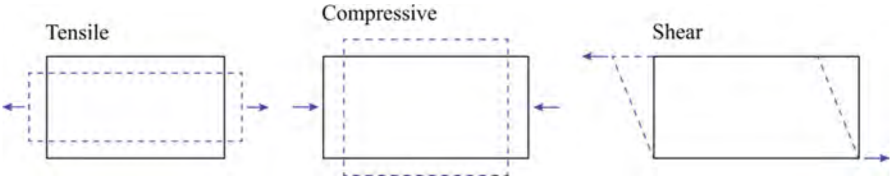

Figure 4.7. The type of deformation produced by the three different types of stress—tensile stress, compressive stress and shear stress. The bold lines in each of these drawings represent the shape of the original object, while the dotted lines indicate the shape changes produced by the stress.

key stone in brick work. It had the ability to transfer stress [see box 4.2] to the load bearers which were the basic seats in the inside of the bus. People sitting on the outside roof space transferred their weight through the curved roof to the slender upright posts and returning through the curved posts to the base frame of the bus construction. This simple but tried-and-tested design with its easy staircase with handrail, panels, glass, garden seats, short wheel base with two large wheels to the rear and two small wheels to the steering gear was the strongest, lightest passenger carrying vehicle built at that time. Weighing barely 30 cwt [1524 kg], and carrying 26 passengers plus two crew, meant it could be pulled in draught by only two horses which were only changed every 8 to 10 miles. This design proved to be a very efficient way of generating passenger revenue, particularly with the introduction of the modesty boards around the upper deck to hide ladies' ankles. The [board] space proved very productive for the bus companies as it was sold to advertisers and that covered the running costs of the omnibuses, so all the fares they took were pure profit,' explains Tony.

The larger of London's bus companies began phasing out horse buses in favour of mechanised buses between 1910 and 1911, although some smaller operators did not have the financial resources to mechanize so continued running their horse bus services for a few more years. 'The last Garden-seat horse omnibus service ran in London in 1914 (from Somerset House over Waterloo Bridge to Waterloo station) by a private operator Fred Newman who then relinquished his horses to the war office for service. The death knell of the horse bus was the outbreak of the First World War in 1914. All the horses were needed for the war effort—for transportation of guns, munitions, and supplies, and for the cavalry,' says Tony, adding that in any case by this point the volume of passengers requiring transport around the capital was overwhelming and horse transport was totally inadequate as the buses were just too small.

'If you look at transport films taken between 1890 and 1910 the roads are totally chock-a-block with horse buses,' continues Tony. 'A railway carriage would hold sixty people. These little buses could only carry twenty six passengers. So they produced more and more buses to cope with demand. The horse power was increasing and the volume of horse manure was increasing. Congestion was getting worse. The situation couldn't go on. So 1910 was pivotal, as this marked the birth of the petrol-engined motor bus and a motor chassis could hold double the capacity of a horse bus. The first standard motor bus the 'B-type' motor omnibus that was introduced in 1910 by The London General Omnibus Company Limited, with its staircase to the top deck, ran until 1927 and is the foundation for the London buses that we have today.'

4.3 Restoring a vintage diesel bus

In 2003, the Pacific Bus Museum in Fremont, California in the United States acquired one of the most iconic types of American bus—a Greyhound Scenicruiser. Their bus, number 8005, was built by General Motors in 1955 and had served intercity bus operator Greyhound Lines Inc.'s Western region which stretched from Canada in the north to Mexico in the south, and as far east as the middle of Wyoming. Volunteers at the Pacific Bus Museum are currently carrying out a full restoration of the vehicle (see figure 4.8). There is no hard and fast schedule for the restoration because it progresses as the volunteers raise money, but at the time of writing this book, the exterior is complete and the team are now fully focussed on restoring the interior.

'The term 'restored' means a Scenicruiser with all the [original] interior and exterior components there and the exterior not modified. There are probably about 25 of these roadworthy in the United States at present, of which about 10 are in the process of being restored. The majority of Scenicruisers that are still running have been converted into motorhomes. Including these there are about 100 Scenicruisers on the road in total,' says Ron Medaglia, Executive Director of the Pacific Bus Museum.

'The Scenicruiser is the quintessential Greyhound,' continues Ron. 'Everyone from the post-World War II baby boom generation saw them. The Scenicruiser was

Figure 4.8. The Pacific Bus Museum's 1955 Greyhound Scenicruiser, number 8005, at various stages of completion during its ongoing restoration. (a) Rust is visible on some of the bodywork in this picture taken in 2004, the year after the museum took ownership; (b) on static display in 2007 with restoration of the exterior underway; (c) pictured in 2014 with work on the body almost finished; (d) on the road in 2016 with the lining and logos completing the exterior restoration. (All images courtesy of Ron Medaglia. Reproduced with permission.)

instantly recognisable and stood out quite prominently. It was a bus that really put Greyhound on the map in the 1950s. They were very innovative mechanically and design-wise.'

The Scenicruiser owes its unique shape in part to US industrial designer Raymond Loewy (1894–1986), a French émigré who also designed streamlined locomotives along with a host of other products ranging from refrigerators to cigarette packets. 'Loewy's influence in the design of the Scenicruiser prototype, General Motors GX-2 model, led to the iconic design of the bus with the driver area on one level and the step up to the other level. That design was really ahead of its time. It was instantly recognisable and that added to the appeal of the bus,' says Ron.

'When I was a child I would see these buses going up and down the highway and think that one day I would ride on one,' continues Ron, who worked in the transportation industry before retiring and devoting much of his time to the Pacific Bus Museum. 'I started out as a bus cleaner and when I was old enough became a bus driver. I worked for a subsidiary company to Greyhound called The Gray Line which was a sightseeing company that worked in San Francisco. In busy periods in the tourist season when they ran out of buses they would borrow Greyhound

Scenicruisers for the tours, so I sometimes got to drive them. That was a real highlight of my career.'

'One thousand and one Scenicruisers were built between 1954 and 1956 by General Motors exclusively for Greyhound. Greyhound was the biggest intercity bus company in the United States. They ran throughout all the 48 States, and at their height they had over 5500 buses in operation,' says Ron.

'The Scenicruiser was the pride of the fleet and was used on all the long distance routes. The United States from the east coast to the west coast is around 3300 miles (5311 km), and they had some very long routes. The longest bus route ran from San Francisco to Miami, Florida and the bus would run all day and all night.' In the 1960s, Greyhound took advantage of the new Interstate highway system which speeded up the travel time, explains Ron. 'It was the most economical way to travel long distances.'

Scenicruisers ran until the mid-1970s, and were rebuilt several times while they were in service. 'The last ones in service were converted into combo-cars, where they would take out about half of the seats and use that space for a package express. Back in the 1960s Greyhound found their package express business highly profitable. Greyhound ran a service to many places throughout the United States many times during each day, sometimes as frequently as once an hour,' says Ron, adding that this convenience made them very useful for carrying all manner of goods including auto parts, blood for hospitals, and bull semen for farmers, as well as regular packages.

The Pacific Bus Museum's number 8005 seated 47 people, and originally worked for the Pacific Greyhound Lines which ran long distance cross-country routes in California, Nevada and Oregon. When the different Greyhound divisions around the United States were consolidated into four larger divisions in the 1960s, 8005 became a Western Greyhound. 'Our particular bus has a significance to the San Francisco area as in the mid-1960s there was a United States Air Force base called Travis AFB about 55 miles (88.5 km) east of San Francisco that was used as a military airport and a Greyhound bus ran once an hour 24 hours a day to transfer military personnel to the civilian San Francisco International Airport. Duffle bags took up a lot of space so eight Scenicruisers were put on this route and our bus was one of them. The Scenicruisers could accommodate 43 or 47 soldiers plus their bags as they had double the luggage space [see figure 4.9] that regular 35 foot buses had, which could only carry about 25 personnel in a bus that seated 38.'

'Back in the 1950s when they were built the maximum length for a bus was 35 feet (11 m) because the thinking was that the roads could not accommodate anything longer. But these buses were 40 feet (12 m). So Greyhound needed to get permits to run in each of the 48 States because they were longer than the legal limit. Today the standard for a bus is 45 feet (14 m) long primarily because of the better roads now. If you had a bigger bus you could carry more passengers and make more profit.'

This was not the only technological change Greyhound brought in. 'Greyhound had their own ideas and concepts that they wanted to incorporate in their buses. They realised that a 40 foot bus would need to have a more powerful engine than a 35 foot bus to get it down the road way. So their idea was to have a bus with two engines in it. They made a couple of experimental models after World War II that

Figure 4.9. The Greyhound Scenicruiser during its ongoing restoration. In this 2006 image, Pacific Bus Museum volunteer Mike Browne is unloading parts stored in one of the two underfloor luggage areas of the bus. The yellow electrical cord is being used to provide electricity to a portable light to illuminate the interior. (Image courtesy of Ron Medaglia. Reproduced with permission.)

developed these concepts. Their thinking at the time was that there was no commercially available single engine big enough to power a 40 foot bus. They needed enough power to climb hills as well as travel down the highways. The engine also needed to power the air conditioning and other accessories such as the electrical system,' explains Ron.

Greyhound experimented with these two-engined buses but, says Ron, when General Motors built them they warned it would be a problematic and unreliable design. They were soon proved correct. 'The experimental buses contained two four-cylinder General Motors engines. One engine was used to power the bus, the other to assist with powering the bus and to power all the accessories like the air conditioning system. The two engines were sited one each side at the rear of the bus and linked by a fluid coupling. But Greyhound couldn't keep them running. Most of them were out of service by 1959. What saved these buses was General Motors developing the V8 diesel engine [a piston engine with 8 cylinders]. This was significantly more powerful than the six cylinder engines in 35 feet buses. It proved to be one of the most successful engines for buses ever built.'

'So Greyhound repowered all their Scenicruisers between 1961 and 1962. They took out the two engines and put in General Motors V8 diesel engines. It took care of all the problems. These V8 engines developed 318 horsepower [see box 4.1] that powered the air conditioning and the electrical system, and could propel the bus down the road well, and actually saved these buses from being scrapped. I remember the


(a) (b)

Figure 4.10. Greyhound Scenicruisers have an aluminium and steel monocoque construction. (a) Shows reconditioned exterior trim pieces from bus 8005. Each piece was first chemically stripped and cleaned, before being belt sanded with 600 grit sandpaper to remove any scratches and restore the original 'brushed' finish. The pieces were then re-anodized in a clear aluminium anodizing solution; (b) Pacific Bus Museum volunteer Mike Browne bucking a rivet using an air powered rivet gun on a replacement panel on the upper windshield. (All images courtesy of Ron Medaglia. Reproduced with permission.)

advertising campaign in 1962 saying: The Greyhound Scenicruiser 62 new ways better for you. Greyhound operated those buses until 1972 and then began selling them off.'

'All 1001 Scenicruisers initially seated 43 passengers—with 10 passengers on the lower deck and 33 on the upper deck—and had a restroom. In the late 1960s they put extra seats into the upper deck of some of the fleet,' says Ron. This brought the capacity up to 47 passengers.

Restoration of bus 8005 began in 2003 when the Pacific Bus Museum became the fourth owners of the bus. 'We didn't need to tear it down into bits and pieces. This bus was physically in relatively good shape, and was running, when we got it. So we didn't have any missing pieces. We had to refurbish and remove corrosion, and in some cases replace the metal where it had rusted away in certain areas, but that was it,' explains Ron, adding that they were able to work from original maintenance manuals that show how to install and repair mechanical and electrical components on the Scenicruiser. 'We have one [manual] for the original set-up with the twin four-cylinder engines. We also have one for the 1962 rebuild, when they converted all the buses to the V8 engines.'

The first steps for the restoration, the mechanical repairs, were carried out for the Museum by Coach Maintenance Company in Williams, California. 'One of the major things that they repaired was the suspension system. These buses all ride on air bellows. It's called 'air ride'. There are no leaf springs. This improved the ride significantly and was a General Motors design used on almost all their buses after 1953 including the Scenicruisers,' explains Ron.

'We then started focusing on the exterior of the body. This is made of aluminium. There are some critical body parts made from steel for structural integrity but the bus is built like an aeroplane with a monocoque construction. It has aluminium panels of six to eight feet in length riveted together [see figure 4.10]. Underneath there are ribs that encircle the bus from top to bottom. There is no frame on these buses. It has an integral design like an aeroplane. The skin on an aeroplane will hold it all together, and [similarly] the riveted panels in the centre of the bus are critical—if you take them out, the whole bus collapses.'

The advantage of this design is a structurally sound body that is lightweight. 'The combination of the aluminium and the riveted monocoque construction created a bus that weighed 3–4000 pounds [1361–1814 kg] less than a comparable bus built of steel. General Motors had the engineering expertise and financial resources to come up with these designs. No other bus manufacturer could come close to doing this. General Motors used this type of construction up until about 1980. It was very successful as a lightweight vehicle translated to increased efficiency and better fuel mileage. It was a bus that private industry could operate and make a profit,' says Ron, adding that they will be using their Scenicruiser to promote the Museum and also to form part of bus displays.

For the restoration, the volunteers are trying to get all the parts of the bus looking as close to original condition as they can. 'The biggest thing [so far] was repairing the body. We had to remove just about all of the paint on it, and get everything sanded down and prepped for painting. Once we got the bus painted, and recently got the graphics on it, that give us a big boost and was a big advancement in the restoration. We take it out now and it looks pretty much like it looked in the 1960s,' says Ron.

'If there were dents in the body, the aluminium panels were replaced or we put body filler in the dents like you would on a car. Then we painted it. You have to treat the aluminium very carefully. We soda blasted the aluminium window frames to remove the 60 plus years of dirt. Trying to do it by hand would be almost impossible. We used the power tools available now which speeds up a lot of the things that we need to do [see figure 4.11], for example the seat frames were sandblasted to get them clean.'


(a) (b)

Figure 4.11. Modern power tools helped speed up the restoration process. (a) Here Pacific Bus Museum volunteer Mitch Roberts is using an air powered sander to sand the wheel hub before it is repainted; (b) Pacific Bus Museum volunteer Homer Beaudoin cleaning dirt off 8005's rear bumper using a portable gasoline powered pressure washer that pressurizes water through a tip at 2500 psi (17 240 kPa). (All images courtesy of Ron Medaglia. Reproduced with permission.)

Figure 4.12. The wiring for 8005's headlights is visible in this 2007 image of restoration progress. The internal lighting, and the headlights and tail lights run off a 12 V circuit that is powered by a generator which in turn is driven by the engine. (Image courtesy of Ron Medaglia. Reproduced with permission.)

In order to source parts, Ron says they started networking with people mainly via the Internet who have original parts to spare. The Pacific Bus Museum is now in touch with people who own Scenicruisers that are being used solely for parts, which has so far removed the need to make any components from scratch.

As well as the exterior, the volunteers have also been working on the electrical system. 'The entire electrical system for the bus is handled by a large high-capacity gear-driven generator connected directly to the engine,' explains Ron. 'The engine is in the rear and there is a series of belts going to the left and to the right of the engine that power the accessories. On the left side are belts and pulleys that power the fans for the radiator to cool the bus engine, and on the right side there are other belts and pulleys for another fan that controls the air conditioning.'

The internal lighting, headlights (see figure 4.12), and tail lights on the Scenicruiser are all 12 volts. Inside the bus there is general lighting directed upwards from the overhead parcel racks that reflects off the white melamine ceiling. Each seat also has its own individual reading light controlled by a switch.

In order to get the lighting system on 8005 back into working order the volunteers carefully checked all the wiring and replaced any bulbs that were no longer working. 'We can still get the 12 V incandescent automobile type bulbs that would have been used, even though everything today is all LED,' says Ron, adding that fortunately a couple of the volunteers with the Pacific Bus Museum are skilled at handling automotive electrical systems.

'The generator also powers the engine controls and gauges,' continues Ron. 'In the event of a short, or an electric connection not working properly, there are circuit breakers.’ This, he explains, was a development from the previous system used on older buses which contained a set of physical fuses that would blow if there were any shorts or electrical overloads.

‘Because of the size of the fleet, and the commonality between the engines and other components, Greyhound knew what to expect in the way of how long they could run the bus before they needed to replace certain components. The V8 was a very solid engine, and you could get 500 000 miles (804 672 km) out of one of those engines before you would need to overhaul it. The key to just about everything Greyhound did was how long those engines could go. The longer they could keep that engine running and intact the more revenue the bus is going to produce for the company.’

‘After a certain number of miles Greyhound would schedule the buses in for an inspection whether there was anything wrong or not. They would check the components for serviceability, and would replace whatever was worn. They could change out a complete engine, transmission and accessories in about 8 or 9 hours. Greyhound would recondition a lot of the engine parts themselves to reuse them, and rebuilt some of the engines 4, 5 or 6 times. As a consequence some of these engines accumulated two or three million miles by being rebuilt over time,’ says Ron, adding that the robustness was one of the most important features of the Greyhound Scenicruisers and was essential because of the large distances the buses needed to travel on their intercity routes.

‘In the United States you needed a vehicle which was durable and reliable because you needed to run that vehicle at least 200 000 miles or more before you needed to do any major work on it. You are running very many miles and the expectation is that this vehicle and its components whether that’s the engine, the air conditioning, or the electrical system is going to be trouble free,’ says Ron. ‘The old saying goes that a ‘bus isn’t making any money if it’s sitting in the yard’, and Greyhound was very adept at maximising revenue by keeping their Scenicruiser buses running.’

Further Reading

Thompson J 1986 *Horse-drawn Omnibuses* (John Thompson) ISBN: 978-0906922118

von Fange P 2015 *Scenicruising—The Greyhound Scenicruiser Story* (Lulu.com) ISBN: 978-1329425088

Weblinks (live as at June 2018)

Drewitts Carriages
http://www.drewitts-events.com/
Beamish Museum
http://www.beamish.org.uk/
The Lord Mayor’s Show
https://lordmayorsshow.london/
Croford Coachbuilders
http://www.croford-coachbuilders.co.uk/

Hoofs and Wheels: Transportation in the West from the National Cowboy & Western Heritage Museum
https://nationalcowboymuseum.org/explore/hoofs-wheels-transportation-west/
Videos about buses at London Transport Museum
https://www.ltmuseum.co.uk/collections/depot-discovery/road-vehicles
London Bus Museum
https://www.londonbusmuseum.com/
Pacific Bus Museum
http://www.pacbus.org/