Handbook of Vehicle Technology and Modification

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Vehicle Braking Technologies

Drum Brake

A drum brake with the drum removed as used on the rear wheel of a car or truck. Note that in this installation, a cable-operated parking brake uses the service shoes.

A **drum brake** is a brake in which the friction is caused by a set of shoes or pads that press against a rotating drum-shaped part called a brake drum.

The term "drum brake" usually means a brake in which shoes press on the inner surface of the drum. When shoes press on the outside of the drum, it is usually called a clasp brake. Where the drum is pinched between two shoes, similar to a conventional disk brake, it is sometimes called a "pinch drum brake", although such brakes are relatively rare. A related type of brake uses a flexible belt or "band" wrapping around the outside of a drum, called a band brake.

History

The modern automobile drum brake was invented in 1902 by Louis Renault, though a less-sophisticated drum brake had been used by Maybach a year earlier. In the first drum brakes, the shoes were mechanically operated with levers and rods or cables. From the mid-1930s the shoes were operated with oil pressure in a small wheel cylinder and pistons (as in the picture), though some vehicles continued with purely-mechanical systems for decades. Some designs have two wheel cylinders.

The shoes in drum brakes are subject to wear and the brakes needed to be adjusted regularly until the introduction of self-adjusting drum brakes in the 1950s. In the 1960s and 1970s brake drums on the front wheels of cars were gradually replaced with disc brakes and now practically all cars use disc brakes on the front wheels, with many offering disc brakes on all wheels. However, drum brakes are still often used for handbrakes as it has proven very difficult to design a disc brake suitable for holding a car when it is not in use. Moreover, it is very easy to fit a drum handbrake *inside* a disc brake so that one unit serves as both service brake and handbrake.

Early type brake shoes contained asbestos. When working on brake systems of older cars, care must be taken not to inhale any dust present in the brake assembly. The United States Federal Government began to regulate asbestos production, and brake manufacturers had to switch to non-asbestos linings. Owners initially complained of poor braking with the replacements; however, technology eventually advanced to compensate. A majority of daily-driven older vehicles have been fitted with asbestos-free linings. Many other countries also limit the use of asbestos in brakes.

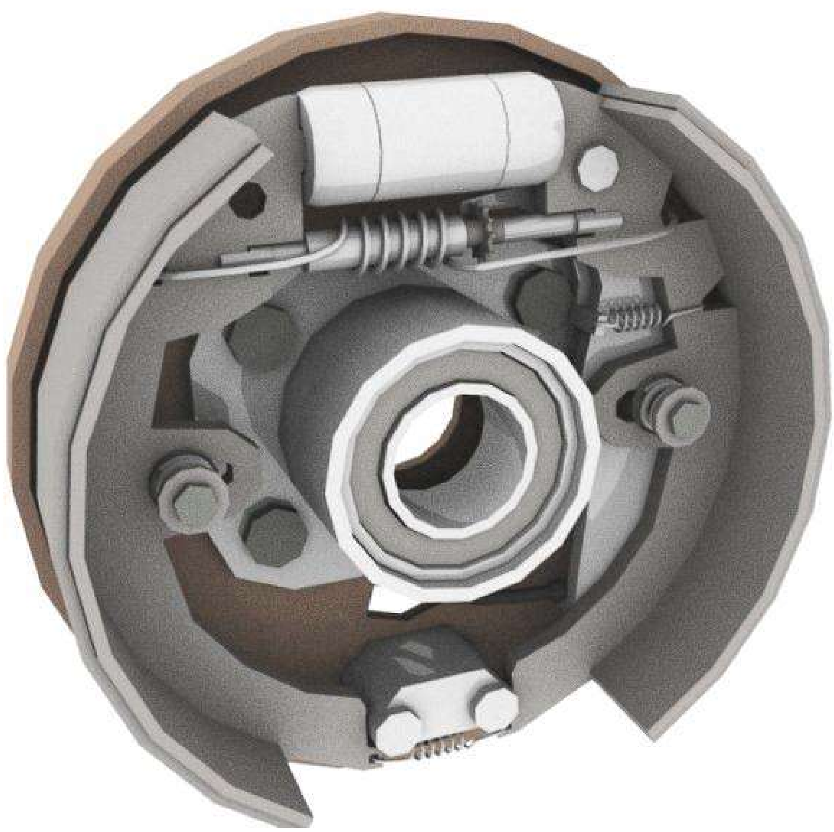
Self-applying characteristic

Drum brakes have a natural "self-applying" characteristic. The rotation of the drum can drag either or both of the shoes into the friction surface, causing the brakes to bite harder, which increases the force holding them together. This increases the stopping power without any additional effort being expended by the driver, but it does make it harder for the driver to modulate the brake's sensitivity. It also makes the brake more sensitive to brake fade, as a decrease in brake friction also reduces the amount of brake assist.

Disc brakes exhibit no self-applying effect because the hydraulic pressure acting on the pads is perpendicular to the direction of rotation of the disc. Disc brake systems usually have servo assistance ("Brake Booster") to lessen the driver's pedal effort, but some disc braked cars (notably race cars) and smaller brakes for motorcycles, etc., do not need to use servos.

Note: In most designs, the "self applying" effect only occurs on one shoe. While this shoe is further forced into the drum surface by a moment due to friction, the opposite effect is happening on the other shoe. The friction force is trying to rotate it away from the drum. The forces are different on each brake shoe resulting in one shoe wearing faster. It is possible to design a two-shoe drum brake where both shoes are self-applying (having separate actuators and pivoted at opposite ends), but these are very uncommon in practice.

Drum brake designs



Rendering of a drum brake

Drum brakes are typically described as either leading/trailing or twin leading.

Rear drum brakes are typically of a leading/trailing design (For Non Servo Systems), or [Primary/Secondary] (For Duo Servo Systems) the shoes being moved by a single double-acting hydraulic cylinder and hinged at the same point. In this design, one of the brake shoes will always experience the self-applying effect, irrespective of whether the vehicle is moving forwards or backwards. This is particularly useful on the rear brakes, where the footbrake (handbrake or parking brake) must exert enough force to stop the vehicle from travelling backwards and hold it on a slope. Provided the contact area of the brake shoes is large enough, which isn't always the case, the self-applying effect can securely hold a vehicle when the weight is transferred to the rear brakes due to the incline of a slope or the reverse direction of motion. A further advantage of using a single hydraulic cylinder on the rear is that the opposite pivot may be made in the form of a double lobed cam that is rotated by the action of the parking brake system.

Front drum brakes may be of either design in practice, but the twin leading design is more effective. This design uses two actuating cylinders arranged so that both shoes will utilize the self-applying characteristic when the vehicle is moving forwards. The brake shoes pivot at opposite points to each other. This gives the maximum possible braking when moving forwards, but is not so effective when the vehicle is traveling in reverse.

The optimum arrangement of twin leading front brakes with leading/trailing brakes on the rear allows for more braking force to be deployed at the front of the vehicle when it is moving forwards, with less at the rear. This helps to prevent the rear wheels locking up, but still provides adequate braking at the rear when it is needed.

The brake drum itself is frequently made of cast iron, although some vehicles have used aluminum drums, particularly for front-wheel applications. Aluminum conducts heat better than cast iron, which improves heat dissipation and reduces fade. Aluminum drums are also lighter than iron drums, which reduces unsprung weight. Because aluminum wears more easily than iron, aluminum drums will frequently have an iron or steel liner on the inner surface of the drum, bonded or riveted to the aluminum outer shell.

Advantages

Drum brakes are still used in some modern cars and smaller (and less-expensive) dirt bikes and ATV's, such as the Honda CRF80F, because of some engineering and cost advantages. Drum brakes allow simple incorporation of a parking brake. They are often applied to the rear wheels since most of the stopping force is generated by the front brakes of the vehicle and therefore the heat generated in the rear is significantly less. Drum brakes are also occasionally fitted as the parking (and emergency) brake even when the rear wheels use disk brakes as the main brakes. In this situation, a small drum is usually fitted within or as part of the brake disk also known as a banksia brake.

In hybrid vehicle applications, wear on braking systems is greatly reduced by energy recovering motor-generators, so some hybrid vehicles such as the GMC Yukon hybrid and Toyota Prius (except the third generation) use drum brakes.

Disc brakes rely on pliability of caliper seals and slight runout to release pads, leading to drag and fuel mileage loss. Drum brake return springs give more positive action and, adjusted correctly, often have less drag when released.

Disadvantages

Drum brakes, like most other types, are designed to convert kinetic energy into heat by friction. This heat is intended to be further transferred to atmosphere, but can just as easily transfer into other components of the braking system.

Brake drums have to be large to cope with the massive forces that are involved, and they must be able to absorb and dissipate a lot of heat. Heat transfer to atmosphere can be aided by incorporating cooling fins onto the drum. However, excessive heating can occur due to heavy or repeated braking which can cause the drum to distort, leading to vibration under braking.

The other consequence of overheating is brake fade. This is due to one of several processes or more usually an accumulation of all of them.

1. When the drums are heated by hard braking, the diameter of the drum increases slightly due to thermal expansion, this means the brakes shoes have to move farther and the brake pedal has to be depressed further.

2. The properties of the friction material can change if heated, resulting in less friction. This is usually only temporary and the material regains its efficiency when cooled, but if the surface overheats to the point where it becomes glazed the reduction in braking efficiency is more permanent. Surface glazing can be worn away with further use of the brakes, but that takes time.

3. Excessive heating of the brake drums can cause the brake fluid to vapourise, which reduces the hydraulic pressure being applied to the brake shoes. Therefore less retardation is achieved for a given amount of pressure on the pedal. The effect is worsened by poor maintenance. If the brake fluid is old and has absorbed moisture it thus has a lower boiling point and brake fade occurs sooner.

Brake fade is not always due to the effects of overheating. If water gets between the friction surfaces and the drum, it acts as a lubricant and reduces braking efficiency. The water tends to stay there until it is heated sufficiently to vapourise, at which point braking efficiency is fully restored. All friction braking systems have a maximum theoretical rate of energy conversion. Once that rate has been reached, applying greater pedal pressure will not result in a change of this rate, and indeed the effects mentioned can substantially reduce it. Ultimately this is what brake fade is, regardless of the mechanism of its causes.

Disc brakes are not immune to any of these processes, but they deal with heat and water more effectively than drums.

Drum brakes can be grabby if the drum surface gets light rust or if the brake is cold and damp, giving the pad material greater friction. Grabbing can be so severe that the tires skid and continue to skid even when the pedal is released. Grabbiness is the opposite of fade: when the pad friction goes up, the self-assisting nature of the brakes causes application force to go up. If the pad friction and self-amplification are high enough, the brake will stay on due to self-application even when the external application force is released.

Re-arcing

Before 1984, it was common to re-arc brake shoes to match the arc within brake drums. This practice, however, was controversial as it removed friction material from the brakes and caused a reduction in the life of the shoes as well as created hazardous asbestos dust. Current design theory is to use shoes for the proper diameter drum, and to simply replace the brake drum when necessary, rather than perform the re-arcing procedure.

Adjustment

Early drum brakes (before about 1955) required periodic adjustment to compensate for drum and shoe wear. If not done sufficiently often long brake pedal travel ("low pedal") resulted. Low pedal can be a severe hazard when combined with brake fade as the brakes can become ineffective when the pedal *bottoms out*.

Self adjusting brakes may use a mechanism that engages only when the vehicle is being stopped from reverse motion. This is a traditional method suitable for use where all wheels use drum brakes (most vehicles now use disc brakes on the front wheels). By operating only in reverse it is less likely that the brakes will be adjusted while hot (when the drums are expanded), which could cause dragging brakes that would accelerate wear and increase fuel consumption.

Self adjusting brakes may also operate by a ratchet mechanism engaged as the hand brake is applied, a means suitable for use where only rear drum brakes are used. If the travel of the parking brake actuator lever exceeds a certain amount, the ratchet turns an adjuster screw that moves the brake shoes toward the drum.

There are different Self Adjusting Brake Systems. Basically can be divided in to RAI and RAD. RAI systems are much more efficient than RAD systems and have built in systems that avoids the systems to recover when the brake is over heating. The most famous RAI are developed by Lucas, Bendix, Bosch, AP. For RAD systems the most famous are Bendix, AP, VAG (Volkswagen) and FORD recovery systems.

The manual adjustment knob is usually at the bottom of the drum and is adjusted via a hole on the opposite side of the wheel. This requires getting underneath the car and moving the clickwheel with a flathead screwdriver. It is important and tedious to adjust each wheel evenly so as to not have the car pull to one side during heavy braking, especially if on the front wheels. Either give each one the same amount of clicks and then perform a road test, or raise each wheel off the ground and spin it by hand measuring how much force it takes and feeling whether or not the shoes are dragging.

Dynamic braking

NS #5348 sporting a Dynamic brake

Dynamic braking is the use of the electric traction motors of a railroad vehicle as generators when slowing the vehicle. It is termed *rheostatic* if the generated electrical power is dissipated as heat in brake grid resistors, and *regenerative* if the power is returned to the supply line. Dynamic braking lowers the wear of friction-based braking components, and additionally regeneration can also lower energy consumption.

Principle of operation

During braking, the motor fields are connected across either the main traction generator (diesel-electric loco) or the supply (electric locomotive) and the motor armatures are connected across either the brake grids or supply line. The rolling locomotive wheels turn the motor armatures, and if the motor fields are now excited, the motors will act as generators.

For a given direction of travel, current flow through the motor armatures during braking will be opposite to that during motoring. Therefore, the motor exerts torque in a direction that is opposite from the rolling direction. Braking effort is proportional to the product of the magnetic strength of the field windings, times that of the armature windings.

For permanent magnet motors, dynamic braking is easily achieved by shorting the motor terminals, thus bringing the motor to a fast abrupt stop. This method, however, dissipates all the energy as heat in the motor itself, and so cannot be used in anything other than low-power intermittent applications due to cooling limitations. It is not suitable for traction applications.

Rheostatic braking

The electrical energy produced by the motors is dissipated as heat by a bank of onboard resistors. Large cooling fans are necessary to protect the resistors from damage. Modern systems have thermal monitoring, so if the temperature of the bank becomes excessive, it will be switched off, and the braking will revert to air only.

Regenerative braking

In electrified systems the similar process of **regenerative braking** is employed whereby the current produced during braking is fed back into the power supply system for use by other traction units, instead of being wasted as heat. It is normal practice to incorporate both regenerative and rheostatic braking in electrified systems. If the power supply system is not *"receptive"*, i.e. incapable of absorbing the current, the system will default to rheostatic mode in order to provide the braking effect.

Yard locomotives with onboard energy storage systems which allow the recovery of some of this energy which would otherwise be wasted as heat are now available. The Green Goat model, for example, is being used by Canadian Pacific Railway, BNSF Railway, Kansas City Southern Railway and Union Pacific Railroad.

Blended braking

A picture of an ex-Connex Class 466 EMU at Blackfriars station in the year 2006. The popular Class 466 EMUs use Dynamic blended braking.

Dynamic braking alone is insufficient to stop a locomotive, as its braking effect rapidly diminishes below about 10 to 12 miles per hour (16 to 19 km/h). Therefore it is always used in conjunction with the regular air brake. This combined system is called **blended braking**. Li-ion batteries have also been used to store energy for use in bringing trains to a complete halt.

Although blended braking combines both dynamic and air braking, the resulting braking force is designed to be the same as what the air brakes on their own provide. This is achieved by maximizing the dynamic brake portion, and automatically regulating the air brake portion, as the main purpose of dynamic braking is to reduce the amount of air braking required. This conserves air, and minimizes the risks of over-heated wheels. One locomotive manufacturer, Electro-Motive Diesel (EMD), estimates that dynamic braking provides between 50% to 70% of the braking force during blended braking.

Self-load test

It is possible to use the brake grids as a form of dynamometer or load bank to perform a *"self load"* test of locomotive engine horsepower. With the locomotive stationary, the main generator (MG) output is connected to the grids instead of the traction motors. The grids are normally large enough to absorb the full engine output power, which is calculated from MG voltage and current output.

Hydrodynamic braking

Diesel engined locomotives with hydraulic transmission may be equipped for hydrodynamic braking. In this case, the torque converter or fluid coupling acts as a retarder in the same way as a water brake. Braking energy heats the hydraulic fluid, and the heat is dissipated (via a heat exchanger) by the engine cooling radiator. The engine will be idling (and producing little heat) during braking, so the radiator is not overloaded.

Anti-lock braking system

An **anti-lock braking system** (**ABS**) is a safety system that allows the wheels on a motor vehicle to continue interacting tractively with the road surface as directed by driver steering inputs while braking, preventing the wheels from locking up (that is, ceasing rotation) and therefore avoiding skidding.

An ABS generally offers improved vehicle control and decreases stopping distances on dry and slippery surfaces for many drivers; however, on loose surfaces like gravel or snow-covered pavement, an ABS can significantly increase braking distance, although still improving vehicle control.

Since initial widespread use in production cars, anti-lock braking systems have evolved considerably. Recent versions not only prevent wheel lock under braking, but also electronically control the front-to-rear brake bias. This function, depending on its specific capabilities and implementation, is known as electronic brakeforce distribution (EBD), traction control system, emergency brake assist, or electronic stability control (ESC).

History

Early systems

The ABS was first developed for aircraft use in 1929 by the French automobile and aircraft pioneer, Gabriel Voisin, as threshold braking on airplanes is nearly impossible. An early system was Dunlop's Maxaret system, which was introduced in the 1950s and is still in use on some aircraft models. These systems use a flywheel and valve attached to a hydraulic line that feeds the brake cylinders. The flywheel is attached to a drum that runs at the same speed as the wheel. In normal braking, the drum and flywheel should spin at the same speed. However, if a wheel were to slow down, then the drum would do the same, leaving the flywheel spinning at a faster rate. This causes the valve to open, allowing a small amount of brake fluid to bypass the master cylinder into a local reservoir, lowering the pressure on the cylinder and releasing the brakes. The use of the drum and flywheel meant the valve only opened when the wheel was turning. In testing, a 30% improvement in braking performance was noted, because the pilots immediately applied full brakes instead of slowly increasing pressure in order to find the skid point. An additional benefit was the elimination of burned or burst tires.

In 1958, a Royal Enfield Super Meteor motorcycle was used by the Road Research Laboratory to test the Maxaret anti-lock brake. The experiments demonstrated that anti-lock brakes can be of great value to motorcycles, for which skidding is involved in a high proportion of accidents. Stopping distances were reduced in most of the tests compared with locked wheel braking, particularly on slippery surfaces, in which the improvement could be as much as 30 percent. Enfield's technical director at the time, Tony Wilson-Jones, saw little future in the system, however, and it was not put into production by the company.

A fully mechanical system saw limited automobile use in the 1960s in the Ferguson P99 racing car, the Jensen FF, and the experimental all wheel drive Ford Zodiac, but saw no further use; the system proved expensive and unreliable in automobile use.

Modern systems

Chrysler, together with the Bendix Corporation, introduced a computerized, three-channel, four-sensor all-wheel ABS called "Sure Brake" for its 1971 Imperial. It was available for several years thereafter, functioned as intended, and proved reliable. In 1971, General Motors introduced the "Trackmaster" rear-wheel only ABS as an option on their Rear-wheel drive Cadillac models. In the same year, Nissan offered an EAL (Electro Anti-lock System) as an option on the Nissan President, which became Japan's first electronic ABS.

In 1975, Robert Bosch took over the European company Teldix and all patents registered by the joint-venture and used this acquisition to build the base of the ABS introduced on the market some years later.

In 1978, the German firms Bosch and Daimler-Benz co-developed an ABS technology that begun in the early 1970s, and introduced the first completely electronic four-wheeled multi-channel ABS in trucks and the Mercedes-Benz S-Class.

ABS brakes on a BMW motorcycle

In 1988, BMW introduced the first motorcycle with an electronic-hydraulic ABS: the BMW K100. Honda followed suit in 1992 with the launch of its first motorcycle ABS on the ST1100 Pan European. In 2007, Suzuki launched its GSF1200SA (Bandit) with an ABS. In 2005, Harley-Davidson began offering ABS as an option for police bikes. In 2008, ABS became a factory-installed option on all Harley-Davidson Touring motorcycles and standard equipment on select models.

Operation

The anti-lock brake controller is also known as the CAB (Controller Anti-lock Brake).

A typical ABS includes a central electronic control unit (ECU), four wheel speed sensors, and at least two hydraulic valves within the brake hydraulics. The ECU constantly monitors the rotational speed of each wheel; if it detects a wheel rotating significantly slower than the others, a condition indicative of impending wheel lock, it actuates the valves to reduce hydraulic pressure to the brake at the affected wheel, thus reducing the braking force on that wheel; the wheel then turns faster. Conversely, if the ECU detects a wheel turning significantly faster than the others, brake hydraulic pressure to the wheel is increased so the braking force is reapplied, slowing down the wheel. This process is repeated continuously and can be detected by the driver via brake pedal pulsation. Some anti-lock system can apply or release braking pressure 16 times per second.

The ECU is programmed to disregard differences in wheel rotative speed below a critical threshold, because when the car is turning, the two wheels towards the center of the curve turn slower than the outer two. For this same reason, a differential is used in virtually all roadgoing vehicles.

If a fault develops in any part of the ABS, a warning light will usually be illuminated on the vehicle instrument panel, and the ABS will be disabled until the fault is rectified.

The modern ABS applies individual brake pressure to all four wheels through a control system of hub-mounted sensors and a dedicated micro-controller. ABS is offered or comes standard on most road vehicles produced today and is the foundation for ESC systems, which are rapidly increasing in popularity due to the vast reduction in price of vehicle electronics over the years.

Modern electronic stability control (ESC or ESP) systems are an evolution of the ABS concept. Here, a minimum of two additional sensors are added to help the system work: these are a steering wheel angle sensor, and a gyroscopic sensor. The theory of operation is simple: when the gyroscopic sensor detects that the direction taken by the car does not coincide with what the steering wheel sensor reports, the ESC software will brake the necessary individual wheel(s) (up to three with the most sophisticated systems), so that the vehicle goes the way the driver intends. The steering wheel sensor also helps in the operation of Cornering Brake Control (CBC), since this will tell the ABS that wheels on the inside of the curve should brake more than wheels on the outside, and by how much.

The ABS equipment may also be used to implement a traction control system(TCS) or Anti-Slip Regulation (ASR) on acceleration of the vehicle. If, when accelerating, the tire loses traction, the ABS controller can detect the situation and take suitable action so that traction is regained. Manufacturers often offer this as a separately priced option even though the infrastructure is largely shared with ABS. More sophisticated versions of this can also control throttle levels and brakes simultaneously.

Components

There are four main components to an ABS: speed sensors, valves, a pump, and a controller.

Speed sensors

The anti-lock braking system needs some way of knowing when a wheel is about to lock up. The speed sensors, which are located at each wheel, or in some cases in the differential, provide this information.

Valves

There is a valve in the brake line of each brake controlled by the ABS. On some systems, the valve has three positions:

- In position one, the valve is open; pressure from the master cylinder is passed right through to the brake.
- In position two, the valve blocks the line, isolating that brake from the master cylinder. This prevents the pressure from rising further should the driver push the brake pedal harder.
- In position three, the valve releases some of the pressure from the brake.

Pump

Since the valve is able to release pressure from the brakes, there has to be some way to put that pressure back. That is what the pump does; when a valve reduces the pressure in a line, the pump is there to get the pressure back up.

Controller

The controller is an ECU type unit in the car which receives information from each individual wheel speed sensor, in turn if a wheel loses traction the signal is sent to the controller, the controller will then limit the brakeforce (EBD) and activate the ABS modulator which actuates the braking valves on and off.

Use

There are many different variations and control algorithms for use in an ABS. One of the simpler systems works as follows:

1. The controller monitors the speed sensors at all times. It is looking for decelerations in the wheel that are out of the ordinary. Right before a wheel locks up, it will experience a rapid deceleration. If left unchecked, the wheel would stop much more quickly than any car could. It might take a car five seconds to stop from 60 mph (96.6 km/h) under ideal conditions, but a wheel that locks up could stop spinning in less than a second.
2. The ABS controller knows that such a rapid deceleration is impossible, so it reduces the pressure to that brake until it sees an acceleration, then it increases the pressure until it sees the deceleration again. It can do this very quickly, before the tire can actually significantly change speed. The result is that the tire slows down at the same rate as the car, with the brakes keeping the tires very near the point at which they will start to lock up. This gives the system maximum braking power.
3. When the ABS system is in operation the driver will feel a pulsing in the brake pedal; this comes from the rapid opening and closing of the valves. This pulsing also tells the driver that the ABS has been triggered. Some ABS systems can cycle up to 15 times per second.

Brake types

Anti-lock braking systems use different schemes depending on the type of brakes in use. They can be differentiated by the number of channels: that is, how many valves that are individually controlled—and the number of speed sensors.

Four-channel, four-sensor ABS

This is the best scheme. There is a speed sensor on all four wheels and a separate valve for all four wheels. With this setup, the controller monitors each wheel individually to make sure it is achieving maximum braking force.

Three-channel, three-sensor ABS

This scheme, commonly found on pickup trucks with four-wheel ABS, has a speed sensor and a valve for each of the front wheels, with one valve and one sensor for both rear wheels. The speed sensor for the rear wheels is located in the rear axle. This system provides individual control of the front wheels, so they can both achieve maximum braking force. The rear wheels, however, are monitored together; they both have to start to lock up before the ABS will activate on the rear. With this system, it is possible that one of the rear wheels will lock during a stop, reducing brake effectiveness.

One-channel, one-sensor ABS

This system is commonly found on pickup trucks with rear-wheel ABS. It has one valve, which controls both rear wheels, and one speed sensor, located in the rear axle. This system operates the same as the rear end of a three-channel system. The rear wheels are monitored together and they both have to start to lock up before the ABS kicks in. In this system it is also possible that one of the rear wheels will lock, reducing brake effectiveness. This system is easy to identify. Usually there will be one brake line going through a T-fitting to both rear wheels.

Effectiveness

A 2003 Australian study by Monash University Accident Research Centre found that ABS:

- Reduced the risk of multiple vehicle crashes by 18 percent,
- Reduced the risk of run-off-road crashes by 35 percent.

On high-traction surfaces such as bitumen, or concrete, many (though not all) ABS-equipped cars are able to attain braking distances better (i.e. shorter) than those that would be easily possible without the benefit of ABS. In real world conditions even an alert, skilled driver without ABS would find it difficult, even through the use of techniques like threshold braking, to match or improve on the performance of a typical driver with a modern ABS-equipped vehicle. ABS reduces chances of crashing, and/or the severity of impact. The recommended technique for non-expert drivers in an ABS-equipped car, in a typical full-braking emergency, is to press the brake pedal as firmly as possible and, where appropriate, to steer around obstructions. In such situations, ABS will significantly reduce the chances of a skid and subsequent loss of control.

In gravel, sand and deep snow, ABS tends to increase braking distances. On these surfaces, locked wheels dig in and stop the vehicle more quickly. ABS prevents this from occurring. Some ABS calibrations reduce this problem by slowing the cycling time, thus letting the wheels repeatedly briefly lock and unlock. Some vehicle manufacturers provide an "off-road" button to turn ABS function off. The primary benefit of ABS on such surfaces is to increase the ability of the driver to maintain control of the car rather than go into a skid, though loss of control remains more likely on soft surfaces like gravel or slippery surfaces like snow or ice. On a very slippery surface such as sheet ice or gravel, it is possible to lock multiple wheels at once, and this can defeat ABS (which relies on comparing all four wheels, and detecting individual wheels skidding). Availability of ABS relieves most drivers from learning threshold braking.

A June 1999 National Highway Traffic Safety Administration (NHTSA) study found that ABS increased stopping distances on loose gravel by an average of 22 percent.

According to the NHTSA,

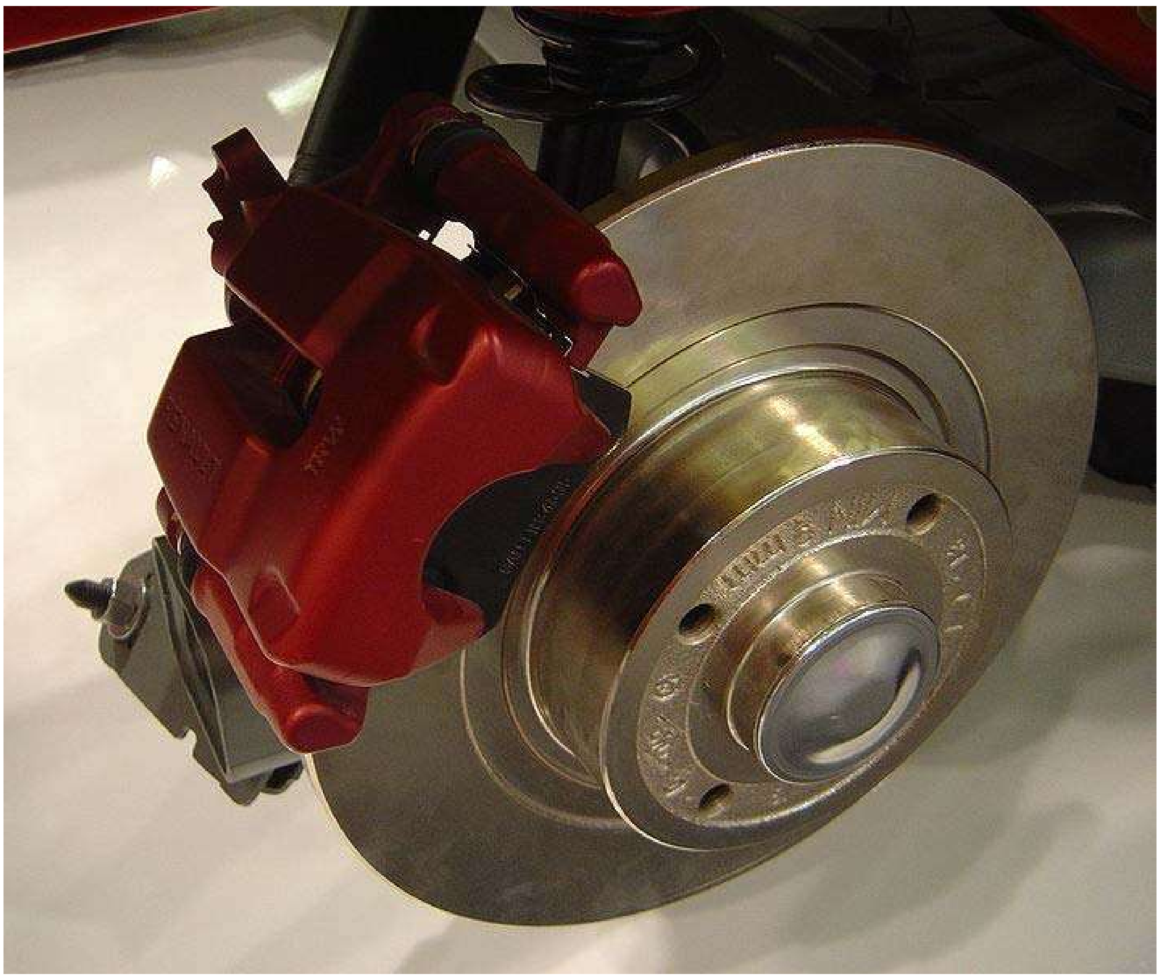
"ABS works with your regular braking system by automatically pumping them. In vehicles not equipped with ABS, the driver has to manually pump the brakes to prevent wheel lockup. In vehicles equipped with ABS, your foot should remain firmly planted on the brake pedal, while ABS pumps the brakes for you so you can concentrate on steering to safety."

When activated, some earlier ABS systems caused the brake pedal to pulse noticeably. As most drivers rarely or never brake hard enough to cause brake lock-up, and a significant number rarely bother to read the car's manual, this may not be discovered until an emergency. When drivers do encounter an emergency that causes them to brake hard, and thus encounter this pulsing for the first time, many are believed to reduce pedal pressure, and thus lengthen braking distances, contributing to a higher level of accidents than the superior emergency stopping capabilities of ABS would otherwise promise. Some manufacturers have therefore implemented a brake assist system that determines that the driver is attempting a "panic stop" (by detecting that the brake pedal was depressed very fast, unlike a normal stop where the pedal pressure would usually be gradually increased, Some systems additionally monitor the rate at the accelerator was released) and the system automatically increases braking force where not enough pressure is applied. Hard or panic braking on bumpy surfaces, because of the bumps causing the speed of the wheel(s) to become erratic may also trigger the ABS. Nevertheless, ABS significantly improves safety and control for drivers in most on-road situations.

Anti-lock brakes are the subject of some experiments centred around risk compensation theory, which asserts that drivers adapt to the safety benefit of ABS by driving more aggressively. In a Munich study, half a fleet of taxicabs was equipped with anti-lock brakes, while the other half had conventional brake systems. The crash rate was substantially the same for both types of cab, and Wilde concludes this was due to drivers of ABS-equipped cabs taking more risks, assuming that ABS would take care of them, while the non-ABS drivers drove more carefully since ABS would not be there to help in case of a dangerous situation. A similar study was carried out in Oslo, with similar results.

Chapter 2

Disc Brake



Close-up of a disc brake on a car

On automobiles, disc brakes are often located within the wheel

The **disc brake** or **disk brake** is a device for slowing or stopping the rotation of a wheel while it is in motion. A brake disc (or *rotor* in U.S. English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon-carbon or ceramic-matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads (mounted on a device called a **brake caliper**) is forced mechanically, hydraulically, pneumatically or electromagnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.

History

Disc-style brakes development and use began in England in the 1890s. The first caliper-type automobile disc brake was patented by Frederick William Lanchester in his Birmingham, UK factory in 1902 and used successfully on Lanchester cars. However, the limited choice of metals in this period, meant that he had to use copper as the braking medium acting on the disc. The poor state of the roads at this time, no more than dusty, rough tracks, meant that the copper wore quickly making the disc brake system non-viable (as recorded in The Lanchester Legacy). It took another half century for his innovation to be widely adopted.

Modern-style disc brakes first appeared on the low-volume Crosley Hotshot in 1949, although they had to be discontinued in 1950 due to design problems. Chrysler's Imperial also offered a type of disc brake from 1949 through 1953, though in this instance they were enclosed with dual internal-expanding, full-circle pressure plates. Reliable modern disc brakes were developed in the UK by Dunlop and first appeared in 1953 on the Jaguar C-Type racing car. The Citroën DS of 1955, with powered inboard front disc brakes, and the 1956 Triumph TR3 were the first European production cars to feature modern disc brakes. The first production car to feature disc brakes at all 4 wheels was the Austin-Healey 100S in 1954. The first British company to market a production saloon fitted with disc brakes to all four wheels was Jensen Motors with the introduction of a Deluxe version of the Jensen 541 with Dunlop disc brakes. The first German production car with disc brakes was the 1961 Mercedes-Benz 220SE coupe featuring British-built Girling units on the front. The next American production automobile equipped with caliper-type disc brakes was the 1963 model year Studebaker Avanti (the Bendix system optional on some of the other Studebaker models). Front disk brakes became standard equipment in 1965 on the Rambler Marlin (the Bendix units were optional on all American Motors "senior" platform models), the Ford Thunderbird, and the Lincoln Continental. A four-wheel disc brake system was also introduced in 1965 on the Chevrolet Corvette Stingray.

Compared to drum brakes, disc brakes offer better stopping performance, because the disc is more readily cooled. As a consequence discs are less prone to the "brake fade" caused when brake components overheat; and disc brakes recover more quickly from immersion (wet brakes are less effective). A drum brake will have at least one leading shoe, which gives a servo-effect. By contrast, a disc brake has no self-servo effect and its braking force is always proportional to the pressure placed on the brake pad by the braking system via any brake servo, braking pedal or lever.

Many early implementations for automobiles located the brakes on the inboard side of the driveshaft, near the differential, but most brakes today are located inside the road wheels. (An inboard location reduces the unsprung weight and eliminates a source of heat transfer to the tires.)

Disc brakes were most popular on sports cars when they were first introduced, since these vehicles are more demanding about brake performance. Discs have now become the more common form in most passenger vehicles, although many (particularly light weight vehicles) use drum brakes on the rear wheels to keep costs and weight down as well as to simplify the provisions for a parking brake. As the front brakes perform most of the braking effort, this can be a reasonable compromise.

Discs

A cross-drilled disc on a modern motorcycle

The design of the disc varies somewhat. Some are simply solid cast iron, but others are hollowed out with fins or vanes joining together the disc's two contact surfaces (usually included as part of a casting process). The weight and power of the vehicle will determine the need for ventilated discs. The "ventilated" disc design helps to dissipate the generated heat and is commonly used on the more-heavily-loaded front discs. The front brakes provide most of the stopping power.

Many higher performance brakes have holes drilled through them. This is known as cross-drilling and was originally done in the 1960s on racing cars. For heat dissipation purposes, cross drilling is still used on some braking components, but is not favored for racing or other hard use as the holes are a source of stress cracks under severe conditions.

Discs may also be slotted, where shallow channels are machined into the disc to aid in removing dust and gas. Slotting is the preferred method in most racing environments to remove gas, water, and de-glaze brake pads. Some discs are both drilled and slotted. Slotted discs are generally not used on standard vehicles because they quickly wear down brake pads; however, this removal of material is beneficial to race vehicles since it keeps the pads soft and avoids vitrification of their surfaces. As a way of avoiding thermal stress, cracking and warping of the disc these are sometimes mounted in a half loose way to the hub with coarse splines. This allows the disc to expand in a controlled symmetrical way and with less unwanted heat transfer to the hub.

On the road, drilled or slotted discs still have a positive effect in wet conditions because the holes or slots prevent a film of water building up between the disc and the pads. Crossdrilled discs may eventually crack at the holes due to metal fatigue. Cross-drilled brakes that are manufactured poorly or subjected to high stresses will crack much sooner and more severely.

The first motorcycles to use disc brakes were racing machines. The first mass-produced road-going motorcycle to sport a disc-brake was the 1969 Honda CB750. Disc brakes are now common on motorcycles, mopeds and even bicycles. Motorcycle disc brakes have become increasingly sophisticated, partly through marketing. Their discs are usually drilled and occasionally slotted. Calipers have evolved from simple "single-pot" units to 2-, 4- and even 6-pot items. It is debatable whether the modern fashions of "radially-mounted calipers" and "wavy discs" significantly improve braking. Since (compared to cars) motorcycles have a higher centre of gravity:wheelbase ratio, they experience more weight transference when braking. A modern sports bike will typically have twin front discs of large diameter, but only a single rear disc that is very much smaller (or even a small rear drum brake). The front brake(s) provide most of the required deceleration; the rear brake serves mainly as to "balance" the motorcycle during braking. If too much braking force is applied to the rear brake, the rear wheel is liable to lock up; so motorcycles should not have oversize rear brakes.

Mountain bike disc brakes range from simple, mechanical (cable) systems, to expensive and powerful, 6-pot (piston) hydraulic disc systems, commonly used on downhill racing bikes. Improved technology has seen the creation of the first vented discs for use on mountain bikes, similar to those on cars, introduced to help avoid heat fade on fast alpine descents. Although less common, discs are also used on road bicycles for all-weather cycling with predictable braking, although drums are sometimes preferred as harder to damage in crowded parking, where discs are sometimes bent. Most bicycle brake discs are made of stainless steel, although some lightweight discs are made of titanium or aluminium. Discs are thin, often about 2 mm. Some use a two-piece floating disc style, others use a floating caliper, others use pads that float in the caliper, and some use one moving pad that makes the caliper slide on its mounts, pulling the other pad into contact with the disc. Because the "motor" is small, an uncommon feature of bicycle brakes is pads that retract to eliminate residual drag when the brake is released. In contrast, most other brakes drag the pads lightly when released.

Disc brakes are increasingly used on very large and heavy road vehicles, where previously large drum brakes were nearly universal. One reason is the disc's lack of self-assist makes brake force much more predictable, so peak brake force can be raised without more risk of braking-induced steering or jackknife on articulated vehicles. Another is disk brakes fade less when hot, and in a heavy vehicle air and rolling drag and engine braking are small parts of total braking force, so brakes are used harder than on lighter vehicles, and drum brake fade can occur in a single stop. For these reasons, a heavy truck with disc brakes can stop in about 120% the distance of a passenger car, but with drums stopping takes about 150% the distance. In Europe, stopping distance regulations essentially require disc brakes for heavy vehicles. In the U.S., drums are allowed and are typically preferred for their lower purchase price, despite higher total lifetime cost and more frequent service intervals.

A railroad bogie and disc brakes

Yet larger discs are used for railroads and some airplanes. Passenger rail cars and light rail often use disc brakes outboard of the wheels, which helps ensure a free flow of cooling air. In contrast, some airplanes have the brake mounted with very little cooling and the brake gets quite hot in a stop, but this is acceptable as the maximum braking energy is very predictable.

For auto use, disc brake discs are commonly manufactured out of a material called grey iron. The SAE maintains a specification for the manufacture of grey iron for various applications. For normal car and light truck applications, the SAE specification is J431 G3000 (superseded to G10). This specification dictates the correct range of hardness, chemical composition, tensile strength, and other properties necessary for the intended use. Some racing cars and airplanes use brakes with carbon fiber discs and carbon fiber pads to reduce weight. Wear rates tend to be high, and braking may be poor or grabby until the brake is hot.

Historically, brake discs were manufactured throughout the world with a strong concentration in Europe, and America. Between 1989 and 2005, manufacturing of brake discs is migrating predominantly to China.

Racing

A reinforced carbon brake disc installed on a Ferrari F430 Challenge race car

In racing and very high performance road cars, other disc materials have been employed. Reinforced carbon discs and pads inspired by aircraft braking systems were introduced in Formula One by Brabham in conjunction with Dunlop in 1976. Carbon-Carbon braking is now used in most top-level motorsport worldwide, reducing unsprung weight, giving better frictional performance and improved structural properties at high temperatures, compared to cast iron. Carbon brakes have occasionally been applied to road cars, by the French Venturi sports car manufacturer in the mid 1990s for example, but need to reach a very high operating temperature before becoming truly effective and so are not well suited to road use. The extreme heat generated in these systems is easily visible during night racing, especially at shorter tracks. It is not uncommon to be able to look at the cars, either live in person or on television and see the brake discs glowing red during application.

Ceramic composites

Ceramic discs are used in some high-performance cars and heavy vehicles.

The first development of the modern ceramic brake was made by British Engineers working in the railway industry for TGV applications in 1988. The objective was to reduce weight, the number of brakes per axle, as well as provide stable friction from very high speeds and all temperatures. The result was a carbon fibre reinforced ceramic process which is now used in various forms for automotive, railway, and aircraft brake applications.

The requirement for a large section of ceramic composite material having very high heat tolerance and mechanical strength often relegates ceramic discs to exotic vehicles where the cost is not prohibitive to the application, and industrial use where the ceramic disc's light weight and low maintenance properties justify the cost relative to alternatives. Composite brakes can withstand temperatures that would make steel discs bendable.

Mercedes Benz AMG Carbon Ceramic brake

Porsche's ceramic composite brakes, known as PCCB (Porsche Composite Ceramic Brakes), are siliconized carbon fiber, with very high temperature capability, a 50% weight reduction over iron rotors (therefore reducing the unsprung weight of the vehicle), a significant reduction in dust generation, substantially increased maintenance intervals, and enhanced durability in corrosive environments over conventional iron rotors. Found on some of their more expensive models, e.g., the Carrera GT, 911 GT2, etc. it is also an optional brake for all street Porsches at added expense. It is generally recognized by the bright yellow paintwork on the aluminum 6-piston calipers that are matched with the rotors. The rotors are internally vented much like cast iron rotors, and also cross-drilled.

Disc damage modes

Discs are usually damaged in one of four ways: scarring, cracking, warping or excessive rusting. Service shops will sometimes respond to any disc problem by changing out the discs entirely, This is done mainly where the cost of a new disc may actually be lower than the cost of labour to resurface the original disc. Mechanically this is unnecessary unless the discs have reached manufacturer's minimum recommended thickness, which would make it unsafe to use them, or vane rusting is severe (ventilated discs only). Most leading vehicle manufacturers recommend brake disc skimming (US: rotor turning) as a solution for lateral run-out, vibration issues and brake noises. The machining process is performed in a brake lathe, which removes a very thin layer off the disc surface to clean off minor damage and restore uniform thickness. Machining the disc as necessary will maximise the mileage out of the current discs on the vehicle.

Excessive lateral run-out (warping)

Measuring this is accomplished using a dial indicator on a fixed rigid base, with the tip perpendicular to the brake disc's face. It is typically measured about 1/2" (12 mm) from the outside diameter of the disc. The disc is spun. The difference between minimum and maximum value on the dial is called lateral runout. Typical hub/disc assembly runout specifications for passenger vehicles are around 0.0020" or 50 micrometers. Runout can be caused either by deformation of the disc itself or by runout in the underlying wheel hub face or by contamination between the disc surface and the underlying hub mounting surface. Determining the root cause of the indicator displacement (lateral runout) requires disassembly of the disc from the hub. Disc face runout due to hub face runout or contamination will typically have a period of 1 minimum and 1 maximum per revolution of the brake disc.

Discs can be machined to eliminate thickness variation and lateral runout. Machining can be done in-situ (on-car) or off-car (bench lathe). Both methods will eliminate thickness variation. Machining on-car with proper equipment can also eliminate lateral runout due to hub-face non-perpendicularity.

Incorrect fitting can distort (warp) discs; the disc's retaining bolts (or the wheel/lug nuts, if the disc is simply sandwiched in place by the wheel, as on many cars) must be tightened progressively and evenly. The use of air tools to fasten lug nuts is extremely bad practice, unless a torque tube is also used. The vehicle manual will indicate the proper pattern for tightening as well as a torque rating for the bolts. Lug nuts should never be tightened in a circle. Some vehicles are sensitive to the force the bolts apply and tightening should be done with a torque wrench.

Often uneven pad transfer is confused for disc warping. In reality, the majority of brake discs which are diagnosed as "warped" are actually simply the product of uneven transfer of pad material.

Uneven pad transfer will often lead to a thickness variation of the disc. When the thicker section of the disc passes between the pads, the pads will move apart and the brake pedal will raise slightly; this is pedal pulsation. The thickness variation can be felt by the driver when it is approximately 0.17 mm or greater (on automobile discs).

This type of thickness variation has many causes, but there are three primary mechanisms which contribute the most to the propagation of disc thickness variations connected to uneven pad transfer. The first is improper selection of brake pads for a given application. Pads which are effective at low temperatures, such as when braking for the first time in cold weather, often are made of materials which decompose unevenly at higher temperatures. This uneven decomposition results in uneven deposition of material onto the brake disc. Another cause of uneven material transfer is improper break in of a pad/disc combination. For proper break in, the disc surface should be refreshed (either by machining the contact surface or by replacing the disc as a whole) every time the pads are changed on a vehicle. Once this is done, the brakes are heavily applied multiple times in succession. This creates a smooth, even interface between the pad and the disc. When this is not done properly the brake pads will see an uneven distribution of stress and heat, resulting in an uneven, seemingly random, deposition of pad material. The third primary mechanism of uneven pad material transfer is known as "pad imprinting." This occurs when the brake pads are heated to the point that the material begins to break-down and transfer to the disc. In a properly broken in brake system (with properly selected pads), this transfer is natural and actually is a major contributor to the braking force generated by the brake pads. However, if the vehicle comes to a stop and the driver continues to apply the brakes, the pads will deposit a layer of material in the shape of the brake pad. This small thickness variation can begin the cycle of uneven pad transfer.

Once the disc has some level of variation in thickness, uneven pad deposition can accelerate, sometimes resulting in changes to the crystal structure of the metal that composes the disc in extreme situations. As the brakes are applied, the pads slide over the varying disc surface. As the pads pass by the thicker section of the disc, they are forced outwards. The foot of the driver applied to the brake pedal naturally resists this change, and thus more force is applied to the pads. The result is that the thicker sections see higher levels of stress. This causes an uneven heating of the surface of the disc, which causes two major issues. As the brake disc heats unevenly it also expands unevenly. The thicker sections of the disc expand more than the thinner sections due to seeing more heat, and thus the difference in thickness is magnified. Also, the uneven distribution of heat results in further uneven transfer of pad material. The result is that the thicker-hotter sections receive even more pad material than the thinner-cooler sections, contributing to a further increase in the variation in the disk's thickness. In extreme situations, this uneven heating can actually cause the crystal structure of the disc material to change. When the hotter sections of the discs reach extremely high temperatures(1200-1300 degrees Fahrenheit), the carbon within the cast iron of the disc will react with the iron molecules to form a carbide known as cementite. This iron carbide is very different from the cast iron the rest of the disc is composed of. It is extremely hard, very brittle, and does not absorb heat well. After cementite is formed, the integrity of the disc is compromised. Even if the disc surface is machined, the cementite within the disc will not wear or absorb heat at the same rate as the cast iron surrounding it, causing the uneven thickness and uneven heating characteristics of the disc to return.

Scarring

Brake discs being polished after scarring occurred

Scarring (US: Scoring) can occur if brake pads are not changed promptly when they reach the end of their service life and are considered worn out. Once enough of the friction material has worn away, the pad's steel backing plate (for glued pads) or the pad retainer rivets (for riveted pads) will bear directly upon the disc's wear surface, reducing braking power and making scratches on the disc. Generally a moderately scarred / scored disc, which operated satisfactorily with existing brake pads, will be equally usable with new pads. If the scarring is deeper but not excessive, it can be repaired by machining off a layer of the disc's surface. This can only be done a limited number of times as the disc has a minimum rated safe thickness. The minimum thickness value is typically cast into the disc during manufacturing on the hub or the edge of the disc. In Pennsylvania, which has one of the most rigorous auto safety inspection programs in North America, an automotive disc cannot pass safety inspection if any scoring is deeper than .015 inches (0.38 mm), and must be replaced if machining will reduce the disc below its minimum safe thickness.

To prevent scarring, it is prudent to periodically inspect the brake pads for wear. A tire rotation is a logical time for inspection, since rotation must be performed regularly based on vehicle operation time and all wheels must be removed, allowing ready visual access to the brake pads. Some types of alloy wheels and brake arrangements will provide enough open space to view the pads without removing the wheel. When practical, pads that are near the wear-out point should be replaced immediately, as complete wear out leads to scarring damage and unsafe braking. Many disc brake pads will include some sort of soft steel spring or drag tab as part of the pad assembly, which is designed to start dragging on the disc when the pad is nearly worn out. The result is a moderately loud metallic squealing noise, alerting the vehicle user that service is required, and this will not normally scar the disc if the brakes are serviced promptly. A set of pads can be considered for replacement if the thickness of the pad material is the same or less than the thickness of the backing steel. In Pennsylvania, the standard is 1/32", or 0.03125 inches (0.794 mm), lining thickness above the rivets on riveted pads and 2/32", or .0625 inches (1.59 mm), lining thickness on bonded pads.

Cracking

Cracking is limited mostly to drilled discs, which may develop small cracks around edges of holes drilled near the edge of the disc due to the disc's uneven rate of expansion in severe duty environments. Manufacturers that use drilled discs as OEM typically do so for two reasons: appearance, if they determine that the average owner of the vehicle model will prefer the look while not overly stressing the hardware; or as a function of reducing the unsprung weight of the brake assembly, with the engineering assumption that enough brake disc mass remains to absorb racing temperatures and stresses. A brake disc is a heat sink, but the loss of heat sink mass may be balanced by increased surface area to radiate away heat. Small hairline cracks may appear in any cross drilled metal disc as a normal wear mechanism, but in the severe case the disc will fail catastrophically. No repair is possible for the cracks, and if cracking becomes severe, the disc must be replaced.

Rusting

The discs are commonly made from cast iron and a certain amount of what is known as "surface rust" is normal. The disc contact area for the brake pads will be kept clean by regular use, but a vehicle that is stored for an extended period can develop significant rust in the contact area that may reduce braking power for a time until the rusted layer is worn off again. Over time, vented brake discs may develop severe rust corrosion inside the ventilation slots, compromising the strength of the structure and needing replacement.

Calipers

Disc brake caliper (twin-pot, floating) removed from brake pad for changing pads

The **brake caliper** is the assembly which houses the brake pads and pistons. The pistons are usually made of aluminium or chrome-plated steel. There are two types of calipers: floating or fixed. A fixed caliper does not move relative to the disc and is, thus, less tolerant of disc imperfections. It uses one or more single or pairs of opposing pistons to clamp from each side of the disc, and is more complex and expensive than a floating caliper. A floating caliper (also called a "sliding caliper") moves with respect to the disc, along a line parallel to the axis of rotation of the disc; a piston on one side of the disc pushes the inner brake pad until it makes contact with the braking surface, then pulls the caliper body with the outer brake pad so pressure is applied to both sides of the disc.

Floating caliper (single piston) designs are subject to sticking failure, which can occur due to dirt or corrosion entering at least one mounting mechanism and stopping its normal movement. This can cause the pad attached to the caliper to rub on the disc when the brake is not engaged, or cause it to engage at an angle. Sticking can occur due to infrequent vehicle use, failure of a seal or rubber protection boot allowing debris entry, dry-out of the grease in the mounting mechanism and subsequent moisture incursion leading to corrosion, or some combination of these factors. Consequences may include reduced fuel efficiency and excessive wear on the affected pad.

Various types of brake calipers are also used on bicycle rim brakes.

Pistons and cylinders

The most common caliper design uses a single hydraulically actuated piston within a cylinder, although high performance brakes use as many as twelve. Modern cars use different hydraulic circuits to actuate the brakes on each set of wheels as a safety measure. The hydraulic design also helps multiply braking force. The number of pistons in a caliper is often referred to as the number of 'pots', so if a vehicle has 'six pot' calipers it means that each caliper houses six pistons.

Brake failure can occur due to failure of the piston to retract - this is usually a consequence of not operating the vehicle during a time that it is stored outdoors in adverse conditions. On high mileage vehicles the piston seals may leak, which must be promptly corrected. The brake disc must have enough surface to perform well and the **coefficient of friction** is the most important factor to be considered when designing a brake system.

Brake pads

The brake pads are designed for high friction with brake pad material embedded in the disc in the process of bedding while wearing evenly. Although it is commonly thought that the pad material contacts the metal of the disc to stop the car, the pads work with a very thin layer of their own material and generate a semi-liquid friction boundary that creates the actual braking force. Friction can be divided into two parts: Adhesive and abrasive. Of course, depending on the properties of the material of both the pad and the disc and the configuration and the usage, pad and disc wear rates will vary considerably. The properties that determine material wear involve trade-offs between performance and longevity. The friction coefficient for most standard pads will be in the region of .40 when used with cast iron discs. Racing pads with high iron content designed for use with cast iron brake discs reach .55 to .60 which gives a very significant increase in braking power and high temperature performance. High iron content racing pads wear down discs very quickly and usually when the pads are worn out so are the discs.

The brake pads must usually be replaced regularly (depending on pad material), and some are equipped with a mechanism that alerts drivers that replacement is needed. Some have a thin piece of soft metal that rubs against the disc when the pads are too thin, causing the brakes to squeal, while others have a soft metal tab embedded in the pad material that closes an electric circuit and lights a warning light when the brake pad gets thin. More expensive cars may use an electronic sensor.

Generally road-going vehicles have two brake pads per caliper, while up to six are installed on each racing caliper, with varying frictional properties in a staggered pattern for optimum performance.

Early brake pads (and linings) contained asbestos. When working on an older car's brakes, care must be taken not to inhale any dust present on the caliper (or drum). Although newer pads can be made of exotic materials like ceramics, kevlar and other plastics, inhalation of brake dust should still be avoided regardless of material.

Brake squeal

Sometimes a loud noise or high pitch squeal occurs when the brakes are applied. Most brake squeal is produced by vibration (resonance instability) of the brake components, especially the pads and discs (known as *force-coupled excitation*). This type of squeal should not negatively affect brake stopping performance. Simple techniques like adding chamfers to linings, greasing or gluing the contact between caliper and the pads (finger to backplate, piston to backplate), bonding insulators (damping material) to pad backplate, inclusion of a brake shim between the brake pad and back plate, etc. may help to reduce squeal. Cold weather combined with high early morning humidity (dew) often makes brake-squeal worse, although the squeal stops when the lining reaches regular operating temperatures. Dust on the brakes may also cause squeal; there are many commercial brake cleaning products that can be used to remove dust and contaminants. Finally, some lining wear indicators, located either as a semi-metallic layer within the brake pad material or with an external squealer "sensor", are also designed to squeal when the lining is due for replacement. The typical external sensor is fundamentally different because it occurs when the brakes are off, and goes away when the brakes are on.

Overall brake squeal can be annoying to the vehicle passengers, passers-by, pedestrians, etc. especially as vehicle designs become quieter. Noise, vibration, and harshness (NVH) are among the most important priorities for today's vehicle manufacturers.

Apart from noise generated from squeal, brakes may also develop a phenomenon called *brake judder* or *shudder*.

Brake judder

Brake judder is usually perceived by the driver as minor to severe vibrations transferred through the chassis during braking.

The judder phenomenon can be classified into two distinct subgroups: *hot* (or *thermal*), or *cold* judder.

Hot judder is usually produced as a result of longer, more moderate braking from high speed where the vehicle does not come to a complete stop. It commonly occurs when a motorist decelerates from speeds of around 120 km/h (74.6 MPH) to about 60 km/h (37.3 MPH), which results in severe vibrations being transmitted to the driver. These vibrations are the result of uneven thermal distributions, or *hot spots*. Hot spots are classified as concentrated thermal regions that alternate between both sides of a disc that distort it in such a way that produces a sinusoidal waviness around its edges. Once the brake pads (friction material/brake lining) comes in contact with the sinusoidal surface during braking, severe vibrations are induced, and can produce hazardous conditions for the person driving the vehicle.

Cold judder, on the other hand, is the result of uneven disc wear patterns or disc thickness variation (DTV). These variations in the disc surface are usually the result of extensive vehicle road usage. DTV is usually attributed to the following causes: waviness of disc surface, misalignment of axis (runout), elastic deflection, wear and friction material transfers.

Brake dust

When braking force is applied, small amounts of material are gradually ground off the brake pads. This material is known as "brake dust" and a fair amount of it usually deposits itself on the braking system and the surrounding wheel. Brake dust can badly damage the finish of most wheels if not washed off. Airborne brake dust is known to be a health hazard, so most repair manuals recommend the use of a chemical 'brake cleaner' instead of compressed air to remove the dust. Different brake pad formulations create different amounts of dust, and some formulations, particularly metallic brake pads, are much more damaging than others. Ceramic brake pads contain significantly fewer metal particles, and therefore produce less corrosion of surrounding metal parts.

Chapter 3

Motorcycle Technology

Motorcycle handlebar

A right clip-on handlebar with twist throttle control, brake lever, and ignition switches

One-piece handlebars on a Ducati bolted to the triple tree with a short riser

Ape Hangers

Motorcycle handlebar refers to the steering mechanism for motorcycles. Handlebars often support part of the rider's weight, and provide a mounting place for controls such as brake, throttle, clutch, horn, light switch, and rear view mirrors.

Types of handlebar

Handlebars come in a variety of types designed for particular types of riding.

- Ape hanger handlebars rise far above the mounting location so that the rider must reach up to use them, hence the name. They are popular on chopper motorcycles. They are available in heights up to 20 inches. Some jurisdictions have regulations on how high the handgrips may be above the seat.
- Z-bar, any sharply angled handlebar with either long or short straight rise sections, which are sharply angled upward from the mounting points and again sharply angled to the handgrip and control area. Z-bars can be ape hangers, but not all ape hangers are Z-bars.
- Beach bars, similar to cruiser bars, slope back toward the rider to allow a relaxed riding position.

- Clip-ons are popular on sport bikes, in which two separate short handles are attached directly to the fork tubes, as opposed to a standard one-piece handlebar attached to the top of the triple tree.
- Clubman bars are common on cafe bikes. They clamp to the triple tree and are angled forward to give the rider a more aggressive riding position.
- Cruiser handlebars tend to be long and slope towards the rear of the motorcycle so that the rider can sit upright.
- Buckhorn handlebars are a variation on the ape hanger, but shorter, and always with a curved back section directly before the part of the bar that mounts the handgrips and controls. These are often thought to be one of the most comfortable type of handlebar, keeping the arms in a very natural and relaxed position in front of the rider. They are often called "mini-apes" (miniature ape hangers), but a true buckhorn must be rounded on top, never with the sharp angles of a Z-bar on the top.
- Drag bars are nearly straight across to create a forward-leaning and aerodynamic riding position.
- Motocross bars are tubular bars that are clamped onto the triple tree. They are common on motocross and off-road motorcycles, as well as dual-sport, streetfighter, and supermoto bikes.

Construction

Handlebars are made from hollow metal tubing, typically aluminium alloys or chrome plated steel but also of carbon fibre and titanium, shaped to the desired contour. Holes may be drilled for the internal routing of control cables such as brake, throttle, and clutch. Risers hold the handlebars above their mounting position on the upper triple tree or the top of the fork, and may be integrated into the bar itself or separate items.

Bar-end weights are often added to either end of the handlebar to damp vibration by moving the bars' resonant frequency away from that generated by the engine. Electrical heating elements may be added under the handlebar grips to provide comfort to the user in cold weather.

Sizes

There are several size parameters that describe most motorcycle handlebars.

- Width from grip to grip may vary from 30.5 inches to 37 inches.
- Rise above mounting location may vary from 0 inches to 20 inches.
- Pullback, the distance grips are behind their mounting location, may vary from 4.25 inches to 17 inches.
- Diameters vary, commonly 7/8 inch, 1 inch, and 1¼ inches, though oversized bars of 1¼, 1½ and 1¾ inches may reduce to 1 inch at the grips so standard controls may be mounted.

Motorcycle fairing

1956 NSU World Record Setting Dolphin II

NSU Sportmax 1955, Dustbin Fairing

BMW K1200GT Touring Motorcycle with Full Fairing

A **Motorcycle fairing** is a shell placed over the frame of some motorcycles, especially racing motorcycles and sports bikes, with the primary purpose to reduce air drag. The secondary functions are the protection of the rider from airborne hazards and wind-induced hypothermia and of the engine components in the case of an accident. There may be a **front fairing**, as well as a **rear fairing** component. A motorcycle windshield may be an integral part of the fairing.

The major benefit of a fairing on Sports Touring and Touring motorcycles is a reduction in fuel consumption. The reduction in aerodynamic drag allows for taller gearing which in turn increases engine life.

History

The importance of streamlining was known very early in the 20th century. Some streamlining was seen on racing motorcycles as early as the 1920s. The effects of aerodynamic drag on motorcycles are very significant.

The term **fairing** came into use in aircraft aerodynamics with regard to smoothing airflow over a juncture of components where airflow was disrupted. Early streamlining was often unsuccessful resulting in instability. Handlebar fairings, such as those on Harley-Davidson Tourers, sometimes upset the balance of a motorcycle inducing wobble. The first factory installed full fairing was that installed on the BMW R100RS introduced in 1976. This marked the beginning of widespread adoption of fairings on sports, and touring types of motorcycles.

Types

- **Streamliner**: This is a full fairing as found on land speed record machines. The entire body of the motorcycle is covered to provide the lowest CD ratio attainable. The NSU Dolphin II (Delphin II) is a streamliner.
- **Dustbin fairing**: A single-piece, streamlined shell covering the front half of a motorcycle resembling the nose of an aircraft, sometimes politely referred to as "**torpedo fairing**". It dramatically reduced the frontal drag, but it was banned by FIM from racing in 1958, because it was thought that the frontal point of wind pressure made them highly unstable even with small amounts of yaw. Other reasons cited for the ban were to ensure adequate steering range (lock-to-lock) and stability against crosswinds. FIM regulations forbid streamlining beyond the wheel spindles and require the rider's arms and legs to be visible from the side.

- **Dolphin fairing**: It was called so because in early models the front wheel mud guard streamlined with the rising windshield part of the fairing resembled the dolphin's beak from the side view. They had become the norm since the ban of the dustbins.

Harley-Davidson police motorcycle with "batwing" fairing

- **Full-fairing**: Bodywork that covers both upper and lower portions of the motorcycle, as distinct from a half fairing, which only has an upper section, and the lower half of the motorcycle is exposed. The fairing on a race or sport bike is meant as an aerodynamic aid, so the windscreen is rarely looked through. If the rider is sitting up at speed he will be buffeted by his rapid progress through the air and act as a parachute (slowing the bike) while if the rider lies flat on the tank behind the windscreen he generates much less aerodynamic drag. The high windscreen and handle-bar width of a touring fairing protect the upright rider from the worst of this, and the windscreen is functional. Full fairings can also provide protection to the engine and chassis in the event of a crash where the fairings, rather than the engine covers and/or frame, slide on the road.

Suzuki SV650s with half fairing and an aftermarket belly pan

- **Half-fairing**: Fairing that features a windscreen and fairing extending at least below the handlebars, even as far as down to the sides of the cylinder block, though generally half-fairing doesn't cover the sides of the crankcase or gear box. A number of half-faired models have aftermarket kits available to extend the original half-fairing into a full fairing. Due to the popularity of these kits some manufacturers have started to supply their own full-fairing conversion kits and even offer their half-faired models new with a full-fairing kit fitted at the factory.

- **Quarter fairing**: A windscreen and minimal fairing extending around the headlight fixed to the triple clamp.

- **Belly pan**: Quarter and half fairings are often paired with a belly pan below the engine for diverting air flow away from under the engine to reduce aerodynamic lift, as well as cosmetic reasons.

Originally the fairings were cowlings put around the front of the bike, increasing its frontal area. Gradually they had become an integral part of the design. Modern fairings increase the frontal area at most by 5% compared to a naked machine. Fairing may carry headlights, instruments, and other items. If the fairing is mounted on the frame, mounting equipment on the fairing reduces the weight and rotational inertia of the steering assembly, improving the handling.

Materials

ABS plastic (acrylonitrile butadiene styrene). ABS material is commonly used in original equipment "OE" sport bikes and certain aftermarket fairing manufacturers due to its strong, flexible yet light weight properties. The advantage of ABS over other plastics is that it combines the strength and rigidity of acrylonitrile and styrene with the toughness of butadlene rubber. The proportions of each property vary based on the targeted result.

Fiberglass: A material made of woven fibers, and is used as a reinforcing agent for many polymer products. The composite properly known as glass-reinforced plastic (GRP), is normally referred to by the name of its reinforcing material. (fiberglass). Fiberglass fairings are commonly used on the race track. In most cases fiberglass is lighter, and more durable than ABS Plastic. Damaged fiberglass can be repaired by applying a new layers of woven fiberglass cloth mixed with a polymer such as epoxy, over the damaged area followed sanding and finishing.

ABS production techniques

There are two common methods of producing ABS plastic fairing: injection and compression. Injection Molds-ABS plastic is melted and injected into mold cavity. Constant pressure is applied to allow for material shrinkage. The plastic then cools and hardens in the mold. Injection molds allows for uniform thickness throughout the entire piece. It gives the most accurate end product that fits well. Compression Molds -The plastic is generally preheated is placed into a heated metal mold cavity and pressure is applied to force the plastic to contract and take the shape of the mold. Heat and pressure is kept until the plastic cures the mold. The excess plastic is cut away and removed from the mold.

> Disadvantages: to compression mold include varying product consistency and flashing issues (excess material attached to the molded part needs to be removed where two or more parts of the mold meet)

Swingarm

Plunger suspension on a 1953 BMW R51/3

A **swingarm** (originally known as a swing fork) is the main component of the rear suspension of most modern motorcycles and ATVs. It is used to hold the rear axle firmly while pivoting vertically to allow the suspension to absorb bumps in the road.

Originally there was no rear suspension **-** the frame design being a stronger version of a bicycle frame. Many types of suspension were tried including Indian's leaf spring suspended swingarm, and Matchless's cantilevered coiled spring swingarm. Immediately prior to and after WWII the **"plunger"** system in which the axle moved up and down two vertical posts became commonplace. In the latter, the movement in each direction was against coiled springs.

Some manufacturers such as Greeves used swingarm designs for the front forks which made them more robust than telescopic forks. The swingarm has also been used for the front suspension of scooters. In this case it aids in simplifying maintenance.

Swingarm types

Swingarms have come in several forms:

Swinging fork - the original version consisting of a pair of parallel pipes holding the rear axle at one end and pivoting at the other. A pair of shock absorbers are mounted just before the rear axle and attached to the frame below the seat rail.

Cantilever - An extension of the swinging fork where a triangulated frame transfers swing arm movement to compress shock absorber/s generally mounted in front of the swingarm. The HRD-Vincent Motorcycle is a famous early form of this type of swingarm, though Matchless used it earlier and Yamaha subsequently. The Harley-Davidson Softail is another form of this swingarm though working in reverse with the shock absorbers being extended rather than compressed.

Single-sided swingarms allow the rear wheel to be mounted like those of an automobile.

BMW's Paralever rear suspension on an R1200RT

Moto Guzzi's *CRDS* variant of the BMW Paralever

Parallelogram Suspension was first introduced commercially in 1985 on the Magni "Le Mans". Magni called the system *Parallelogrammo*. This new suspension system eliminated the torque reactions normally associated with shaft drive motorcycles and enabled the bike to perform similarly to a chain-drive unit. Similar systems have been developed by other manufacturers.

Paralever is BMW's version of the system. It allows the driveshaft to pivot along the same axis as the sprung rear frame due to the addition of second link between the rear drive and transmission. Paralever was originally introduced in 1988 R80GS and R100GS motorcycles and provides a reduction in the phenomenon known as "shaft jacking" where the rear of the motorcycle would lift skyward under certain riding conditions.

Moto Guzzi has introduced a variant of the system it named the *Compact Reactive Drive Shaft* system (patented and named Ca.R.C.). The main difference is that the driveshaft is free to float into its structure providing much softer feedback from transmission. Additionally, the upper arm of the Ca.R.C. is not part of the structure but just a guide to close the geometry of the suspension (it means that, differently from BMW version, the suspension will work also with a broken upper arm).

Drag racing motorcycles will often use longer swingarms to keep their center of gravity, i.e. the engine, as forward as possible to reduce the tendency to wheelie at the start.

Chapter 4

Driverless Car

A robotic Volkswagen Passat shown at Stanford University

A **driverless car** is a vehicle equipped with an autopilot system, which is capable of driving from one point to another without input from a human operator.

This technology is distinct from vehicles with a remote operator such as Bombardier Advanced Rapid Transit Systems.

The proposed advantages include:

- transporting loads in dangerous zones such as battlefields or disaster-zones.

- reducing the costs and inconvenience of employing drivers (for example for public transport or commercial vehicles),
- managing traffic flow to increase road capacity
- relieving vehicle occupants from driving and navigating chores, so allowing them to concentrate on other tasks or to take rest during their journeys,
- reducing directional steering and velocity errors and corrections implicit in manually controlled vehicles
    - to avoid accidents,
    - to accurately align vehicles with platforms to facilitate disabled access and cargo loading
    - to reduce lane width and safety margins (especially bus-lanes on narrow roads, as in Castellon, Spain)

Some proposed systems depend on infrastructure-based guidance systems (i.e. systems embedded in or near the road itself), while more advanced systems propose to simulate human perception and decision-making during steering of a car via advanced computer software linked to a range of sensors such as cameras, radar and GPS.

While common in science fiction and futurist scenarios for a long time, driverless cars in an unstructured (i.e. non-prepared, constantly changing) free environment are still in their infancy as of 2011, and there are no vehicles in existence that are approved for use in environments where they would encounter normal human drivers - though much progress was made in the late 2000s. Driverless passenger car programs include the 800 million EC EUREKA Prometheus Project on autonomous vehicles, the 2getthere passenger vehicles from the Netherlands, the ARGO research project from Italy, the DARPA Grand Challenge from the USA and Google driverless car.

History

An early representation of the driverless car was Norman Bel Geddes's Futurama exhibit sponsored by General Motors at the 1933 World's Fair, which depicted electric cars powered by circuits embedded in the roadway and controlled by radio.

The history of autonomous vehicles starts in 1977 with the Tsukuba Mechanical Engineering Lab in Japan. On a dedicated, clearly marked course it achieved speeds of up to 30 km/h (20 miles per hour), by tracking white street markers (special hardware was necessary, since commercial computers were much slower than they are today).

In the 1980s a vision-guided Mercedes-Benz robot van, designed by Ernst Dickmanns and his team at the Bundeswehr University of Munich in Munich, Germany, achieved 100 km/h on streets without traffic. Subsequently, the European Commission began funding the 800 million Euro EUREKA Prometheus Project on autonomous vehicles (1987–1995).

Also in the 1980s the DARPA-funded Autonomous Land Vehicle (ALV) in the United States achieved the first road-following demonstration that used laser radar

(Environmental Research Institute of Michigan), computer vision (Carnegie Mellon University and SRI), and autonomous robotic control (Carnegie Mellon and Martin Marietta) to control a driverless vehicle up to 30 km/h. In 1987, HRL Laboratories (formerly Hughes Research Labs) demonstrated the first off-road map and sensor-based autonomous navigation on the ALV. The vehicle travelled over 600m at 3 km/h on complex terrain with steep slopes, ravines, large rocks, and vegetation.

In 1994, the twin robot vehicles VaMP and Vita-2 of Daimler-Benz and Ernst Dickmanns of UniBwM drove more than one thousand kilometers on a Paris three-lane highway in standard heavy traffic at speeds up to 130 km/h, albeit semi-autonomously with human interventions. They demonstrated autonomous driving in free lanes, convoy driving, and lane changes left and right with autonomous passing of other cars.

In 1995, Dickmanns re-engineered autonomous S-Class Mercedes-Benz took a 1600 km trip from Munich in Bavaria to Copenhagen in Denmark and back, using saccadic computer vision and transputers to react in real time. The robot achieved speeds exceeding 175 km/h on the German Autobahn, with a mean time between human interventions of 9 km, or 95% autonomous driving. Again it drove in traffic, executing manoeuvres to pass other cars. Despite being a research system without emphasis on long distance reliability, it drove up to 158 km without human intervention.

In 1995, the Carnegie Mellon University Navlab project achieved 98.2% autonomous driving on a 5000 km (3000-mile) "No hands across America" trip. This car, however, was semi-autonomous by nature: it used neural networks to control the steering wheel, but throttle and brakes were human-controlled.

From 1996–2001, Alberto Broggi of the University of Parma launched the ARGO Project, which worked on enabling a modified Lancia Thema to follow the normal (painted) lane marks in an unmodified highway. The culmination of the project was a journey of 2,000 km over six days on the motorways of northern Italy dubbed MilleMiglia in Automatico, with an average speed of 90 km/h. 94% of the time the car was in fully automatic mode, with the longest automatic stretch being 54 km. The vehicle had only two black-and-white low-cost video cameras on board, and used stereoscopic vision algorithms to understand its environment, as opposed to the "laser, radar - whatever you need" approach taken by other efforts in the field.

Three US Government funded military efforts known as Demo I (US Army), Demo II (DARPA), and Demo III (US Army), are currently underway. Demo III (2001) demonstrated the ability of unmanned ground vehicles to navigate miles of difficult off-road terrain, avoiding obstacles such as rocks and trees. James Albus at NIST provided the Real-Time Control System which is a hierarchical control system. Not only were individual vehicles controlled (e.g. throttle, steering, and brake), but groups of vehicles had their movements automatically coordinated in response to high level goals.

In 2002, the DARPA Grand Challenge competitions were announced. The 2004 and 2005 DARPA competitions allowed international teams to compete in fully autonomous vehicle races over rough unpaved terrain and in a non-populated suburban setting. The 2007 DARPA challenge, the DARPA urban challenge, involved autonomous cars driving in an urban setting.

In 2008, General Motors stated that they will begin testing driverless cars by 2015, and they could be on the road by 2018.

In 2010 VisLab ran VIAC, the VisLab Intercontinental Autonomous Challenge, a 13,000 km test run of autonomous vehicles. The four driverless electric vans successfully ended the drive from Italy to China via the arriving at the Shanghai Expo on 28 October.

Recent projects

The work done so far varies significantly in its ambition and its demands in terms of modification of the infrastructure. Broadly, there are three approaches:

- Fully autonomous vehicles
- Various enhancements to the infrastructure (either an entire area, or specific lanes) to create a self-driving closed system.
- "assistance" systems that incrementally remove requirements from the human driver (e.g. improvements to cruise control)

An important concept that cuts across several of the efforts is vehicle **platoons**. In order to better utilize road-space, vehicles are assembled into ad-hoc train-like "platoons", where the driver (either human or automatic) of the first vehicle makes all decisions for the entire platoon. All other vehicles simply follow the lead of the first vehicle.

Fully autonomous

Fully autonomous driving requires a car to drive itself to a pre-set target using unmodified infrastructure. The final goal of safe door-to-door transportation in arbitrary environments is not yet reached though.

Vehicles for paved roads

- Google driverless car, with a test fleet of autonomous vehicles that by October 2010 have driven 140,000 miles (230,000 km) without any incidents.
- The 800 million Euro EUREKA Prometheus Project on autonomous vehicles (1987–1995). Among its culmination points were the twin robot vehicles VITA-2 and VaMP of Daimler-Benz and Ernst Dickmanns, driving long distances in heavy traffic.
- The VIAC Challenge, in which 4 vehicles drove from Italy to China on a 13,000 kilometres (8,100 mi) trip with only limited occasions intervene by human, such as in the Moscow traffic jams and when passing toll stations. This is the longest-ever trip by an unmanned vehicle.

- The third competition of the DARPA Grand Challenge held in November 2007. 53 teams qualified initially, but after a series of qualifying rounds, only eleven teams entered the final race. Of these, six teams completed navigating through the non-populated urban environment, and the Carnegie Mellon University team won the $2 million prize.
- The ARGO vehicle is the predecessor of the BRAiVE vehicle, both from the University of Parma's VisLab. Argo was developed in 1996 and demonstrated to the world in 1998; BRAiVE was developed in 2008 and firstly demonstrated in 2009 at the IEEE IV conference in Xi'an, China.
- Stanford Racing Team's Junior car is an autonomous driverless car for paved roads. It is intended for civilian use.
- The Volkswagen Golf GTI 53+1 is a modified Volkswagen Golf GTI capable of autonomous driving. The Golf GTI 53+1 features a implemented system that can be integrated into any car. This system is based around the MicroAutoBox from dSpace. This, as it was intended to test VW hardware without a human driver (for consistent test results).
- The Audi TTS Pikes Peak is a modified Audi TTS, working entirely on GPS, and thus without additional sensors. The car was designed by Burkhard Huhnke of Volkswagen Research.
- Stadtpilot, Technical University Braunschweig
- AutoNOMOS - part of the Artificial Intelligence Group of the Freie Universität Berlin

Free-ranging vehicles

There are four clusters of activity relating to free-ranging off-road cars. Some of these projects are military-oriented.

- US military DARPA Grand Challenge

  The US Department of Defense announced on the July 30, 2002 a "Grand Challenge", for US-based teams to produce a vehicle that could autonomously navigate and reach a target in the desert of the south western USA.
  In March 2004, the first competition was held, for a prize-money of $1 million. Not one of the 25 entrants completed the course. However, in the second competition held in October 2005 five different teams completed the 135-mile (217 km) course, and the Stanford University team won the $2 million prize. November 3rd, 2007, the third competition was held and $3.5 million dollar in cash prizes, trophies and medals were awarded. Six driverless vehicles were able to complete the 55 miles (89 km) of urban traffic in the 2007 DARPA Urban Challenge rally style race. 1st Place - Tartan Racing, Pittsburgh, PA; 2nd Place - Stanford Racing Team, Stanford, CA; 3rd Place - Victor Tango, Blacksburg, VA.

- European Land-Robot Trial (ELROB)

  The German Department of Defense held an exhibition trade show (ELROB) for demonstrating automated vehicles in May 2006. The event included various military automated and remotely-operated robots, for various military uses. Some of the systems on display could be ordered and implemented immediately. In August 2007 a civilian version of the event was held in Switzerland.
  The Smart team from Switzerland presented "a Vehicle for Autonomous Navigation and Mapping in Outdoor Environments".

- The Israeli Military-Industrial Complex

  As a followup from its success with Unmanned Combat Air Vehicles, and following the construction of the Israeli West Bank barrier there has been significant interest in developing a fully automated border-patrol vehicle. Two projects, by Elbit Systems and Israel Aircraft Industries are both based on the locally-produced Armored "Tomcar" and have the specific purpose of patrolling barrier fences against intrusions.
  The "SciAutonics II" team in the 2004 DARPA Challenge used Elbit's version of the Tomcar.

- Korean Autonomous Vehicle Competition (AVC) organized by Hyundai Kia Automotive Group

  In November 2010, the first competition was held, for a winning prize-money of $100 thousand, and the Hanyang University A1 team won the $100 thousand prize.

Pre-built infrastructure

The following projects were conceived as practical attempts to use available technology in an incremental manner to solve specific problems, like transport within a defined campus area, or driving along a stretch of motorway. The technologies are proven, and the main barrier to widespread implementation is the cost of deploying the infrastructure. Such systems already function in many airports, on railroads, and in some European towns.

Dual mode transit - monorail

There is a family of projects, all currently still at the experimental stage, that would combine the flexibility of a private automobile with the benefits of a monorail system. The idea is that privately-owned cars would be built with the ability to dock themselves onto a public monorail system, where they become part of a centrally managed, fully computerized transport system—more akin to a driverless train system (as already found in airports) than to a driverless car. This idea is also known as Dual mode transit.

Groups working on this concept are:

- RUF (Denmark)
- BiWay (UK)
- ATN (New Zealand)
- TriTrack (Texas, United States)

Automated highway systems

Automated highway systems (**AHS**) are an effort to construct special lanes on existing highways that would be equipped with magnets or other infrastructure to allow vehicles to stay in the center of the lane, while communicating with other vehicles (and with a central system) to avoid collision and manage traffic. Like the dual-mode monorail, the idea is that cars remain private and independent, and just use the AHS system as a quick way to move along designated routes. AHS allows specially equipped cars to join the system using special 'acceleration lanes' and to leave through 'deceleration lanes'. When leaving the system each car verifies that its driver is ready to take control of the vehicle, and if that is not the case, the system parks the car safely in a predesignated area.

Some implementations use radar to avoid collisions and coordinate speed.

One example that uses this implementation is the AHS demo of 1997 near San Diego, sponsored by the US government, in coordination with the State of California and Carnegie Mellon University. The test site is a 12-kilometer, high-occupancy-vehicle (HOV) segment of Interstate 15, 16 kilometers north of downtown San Diego. The event generated much press coverage.

This concerted effort by the US government seems to have been pretty much abandoned because of social and political forces, above all else the desire to create a less futuristic and more marketable solution.

As of 2007, a three-year project is underway to allow robot controlled vehicles, including buses and trucks, to use a special lane along 20 Interstate 805. The intention is to allow the vehicles to travel at shorter following distances and thereby allow more vehicles to use the lanes. The vehicles will still have drivers since they need to enter and exit the special lanes. The system is being designed by Swoop Technology, based in San Diego county.

Free-ranging on grid

Frog Navigation Systems (the Netherlands) applies the FROG (**free-ranging on grid**) technology. The technology consists of a combination of autonomous vehicles and a supervisory central system. The company's purpose-built electric vehicles locate themselves using odometry readings, recalibrating themselves occasionally using a "maze" of magnets embedded in the environment, and GPS. The cars avoid collisions with obstacles located in the environment using laser (long range) and ultra-sonic (short-range) sensors.

The vehicles are completely autonomous and plan their own routes from A to B. The supervisory system merely administers the operations and directs traffic where required. The system has been applied both indoors and outdoors, and in environments where 100+ automated vehicles are operational (container port). At this time the system is not suited yet for running the sheer number of vehicles encountered in urban settings. The company also has no intention of developing such technology at this time.

The FROG system is deployed for industrial purposes in factory sites, and is marketed as a pilot public transport system in the city of Capelle aan den IJssel by its subsidiary 2getthere. This system experienced an accident that proved to be caused by a Human error.

Frog Navigation Systems is one of few fully commercial companies in this field.

Driver-assistance

Though these products and projects do not aim explicitly to create a fully autonomous car, they are seen as incremental stepping-stones in that direction. Many of the technologies detailed below will probably serve as components of any future driverless car — meanwhile they are being marketed as gadgets that assist human drivers in one way or another. This approach is slowly trickling into standard cars (e.g. improvements to cruise control).

Driver-assistance mechanisms are of several distinct types, sensorial-informative, actuation-corrective, and systemic.

Sensorial-informative

These systems warn or inform the driver about events that may have passed unnoticed, such as

- Lane Departure Warning System (LDWS), for example from Iteris or Mobileye N.V.
- Rear-view alarm, to detect obstacles behind.
- Visibility aids for the driver, to cover blind spots and enhanced vision systems such as radar, wireless vehicle safety communications and night vision.
- Infrastructure-based, driver warning/information-giving systems, such as those developed by the Japanese government

Actuation-corrective

These systems modify the driver's instructions so as to execute them in a more effective way, for example the most widely deployed system of this type is ABS; conversely power steering is not a control mechanism, but just a convenience - it is not involved in decision making.

- Anti-lock braking system (ABS) (also Emergency Braking Assistance (EBA), often coupled with Electronic brake force distribution (EBD), which prevents the brakes from locking and losing traction while braking. This shortens stopping distances in most cases and, more importantly, allows the driver to steer the vehicle while braking.
- Traction control system (TCS) actuates brakes or reduces throttle to restore traction if driven wheels begin to spin.
- Four wheel drive (AWD) with a centre differential. Distributing power to all four wheels lessens the chances of wheel spin. It also suffers less from oversteer and understeer.
- Electronic Stability Control (ESC) (also known for Mercedes-Benz proprietary Electronic Stability Program (ESP), Acceleration Slip Regulation (ASR) and Electronic differential lock (EDL)). Uses various sensors to intervene when the car senses a possible loss of control. The car's control unit can reduce power from the engine and even apply the brakes on individual wheels to prevent the car from understeering or oversteering.
- Dynamic steering response (DSR) corrects the rate of power steering system to adapt it to vehicle's speed and road conditions.

A review of the overall "feel" to actuation-correction in a Jaguar XK convertible.

Driver-assistance preview from Popular Science (dated 2004).

Note: The electronic differential lock (EDL) employed by Volkswagen is not - as the name suggests - a differential lock at all. Sensors monitor wheel speeds, and if one is rotating substantially faster than the other (i.e. slipping) the EDL system momentarily brakes it. This effectively transfers all the power to the other wheel.

Systemic

- Automatic parking: e.g. technology from Ford or Toyota selling for $700, with a 70% take-up rate. The Lexus LS can park itself (parallel/reverse) via the 'Advanced Parking Guidance System' – though only controlling the steering.
- Follow another car on a motorway ("Enhanced" or "adaptive" cruise control), like The Ford or Vauxhall(GM).
- Nissan's "Distance Control assist"
- Dead Man's Switch; there is a move to introduce deadman's braking into automotive application, primarily heavy vehicles, and there may also be a need to add penalty switches to cruise controls.

Existing and missing technologies

In order to drive a car, a system would need to:

1. Understand its immediate environment (Sensors)
2. Know where it is and where it wants to go (Navigation)
3. Find its way in the traffic (Motion planning)
4. Operate the mechanics of the vehicle (Actuation)

Arguably, 2½ of these problems are already solved: Navigation and Actuation completely, and Sensors partially, but improving fast. The main unsolved part is the motion planning.

Sensors

Sensors employed in driverless cars vary from the minimalist ARGO project's monochrome stereoscopy to Mobileye's inter-modal (video, infra-red, laser, radar) approach. The minimalist approach imitates the human situation most closely, while the multi-modal approach is "greedy" in the sense that it seeks to obtain as much information as is possible by current technology, even at the occasional cost of one car's detection system interfering with another's.

Mobileye N.V. is a technology company that focuses on the development of vision-based Advanced Driver Assistance Systems (ADAS) providing warnings for collision prevention and mitigation. Mobileye offers a wide range of driver safety solutions combining artificial vision image processing, multiple technological applications and information technology. Mobileye's vehicle detection systems, are currently only used for driver assistance, but are eminently suitable for a full-fledged driverless car. This video demonstrates the capabilities of the system: all pedestrians, cars, motorbikes etc. are clearly displayed in video, with a frame around them and the distance between "our" car and the object observed. The system also detects the objects' motion (direction and speed) and can so calculate relative speeds, and predict collisions.

- Japanese infra-red article
- some things from the DARPA challenge....
- Road-sign recognition

Navigation

The ability to plot a route from where the vehicle is to where the user wants to be has been available for several years. These systems, based on the US military's Global Positioning System are now available as standard car fittings, and use satellite transmissions to ascertain the current location, and an on-board street database to derive a route to the target. The more sophisticated systems also receive radio updates on road blockages, and adapt accordingly. There are also sensors that greatly affect the whole nature of it.

Motion planning

- PMP + SLAMMOT

This is current research problem.

Control of vehicle

As automotive technology matures, more and more functions of the underlying engine, gearbox etc. are no longer directly controlled by the driver by mechanical means, but rather via a computer, which receives instructions from the driver as inputs and delivers the desired effect by means of electronic throttle control, and other drive-by-wire elements. Therefore, the technology for a computer to control all aspects of a vehicle is well understood.

Work done in simulation

While developing control systems for real cars is very costly in terms of both time and money, much work can be done in simulations of various complexity. Systems developed using simpler simulators can gradually be transferred to more complex simulators, and in the end to real vehicles. Some approaches that rely on learning requires starting in a simulation to be viable at all, for example evolutionary robotics approaches.

Social impact

Driverless cars may yield advantages of increasing roadway capacity by reducing the distances between cars, reduce congestion by efficiently controlling the flow of traffic, and increase safety by eliminating driver error.

According to urban designer and futurist Michael E. Arth, driverless electric vehicles—in conjunction with the increased use of virtual reality for work, travel, and pleasure—could reduce the world's vehicles (estimated to be 800,000,000) to a fraction of that number within a few decades. Arth claims that this would be possible if almost all private cars requiring drivers, which are not in use and parked 90% of the time, would be traded for public self-driving taxis that would be in near constant use. This would also allow for getting the appropriate vehicle for the particular need—a bus could come for a group of people, a limousine could come for a special night out, and a Segway could come for a short trip down the street for one person. Children could be chauffeured in supervised safety, DUIs would no longer exist, and 41,000 lives could be saved each year in the U.S. alone.

Chapter 5

Automotive Steering Technologies

Power steering

The term **power steering** is usually used to describe a system that provides mechanical steering assistance to the driver of a land vehicle, for example, a car or truck. The power steering system in a vehicle is a type of servomechanism.

For many drivers, turning the steering wheel in a vehicle that doesn't have power steering requires more force (torque) than the driver finds comfortable, especially when the vehicle is moving at a very slow speed. Steering force is very sensitive to the weight of the vehicle, and nearly so much to its length, so this is most important for large vehicles. In a vehicle equipped with power steering, when the driver turns the steering wheel, he feels only a slight retarding force, so a vehicle equipped with power steering can be driven by any healthy driver, even when the vehicle is being parked. This is because the power steering system furnishes most of the energy required to turn the steered wheels of the car.

Most power steering systems in cars and light trucks today are hydraulic (that is, the force to turn the wheels is provided by a hydraulic piston, which is powered by high pressure hydraulic fluid), but in some cars and trucks, the steering force is provided by an electric motor.

History

A steam-powered ship's steering engine, similar in many ways to the power steering system used in modern cars and trucks, was first installed in the SS Great Eastern in 1866.

The earliest known patent for a power steering system for a land vehicle was granted to Frederick W. Lanchester in the UK in February 1902. His invention was to "cause the steering mechanism to be actuated by hydraulic power". R.E. Twyford included a mechanical power steering mechanism as part of his patent for the first four wheel drive system (U.S. Patent 646,477 April 3, 1900). The next design was filed as recorded by the US Patent Office on August 30, 1932, by Klara Gailis, from Belmont, Massachusetts. There is another inventor credited with the invention of power steering by the name of

Charles F. Hammond an American, born in Detroit, who filed similar patents, the first of which was filed as recorded by the Canadian Intellectual Property Office.

Francis W. Davis, an engineer of the truck division of Pierce Arrow began exploring how steering could be made easier, and in 1926 demonstrated the first power steering system. Davis moved to General Motors and refined the hydraulic-assisted power steering system, but the automaker calculated it would be too expensive to produce. Davis then signed up with Bendix, a parts manufacturer for automakers. Military needs during World War II for easier steering on heavy vehicles boosted the need for power assistance on armored cars and tank-recovery vehicles for the British and American armies.

Chrysler Corporation introduced the first commercially available passenger car power steering system on the 1951 Chrysler Imperial under the name "Hydraguide". The Chrysler system was based on some of Davis' expired patents. General Motors introduced the 1952 Cadillac with a power steering system using the work Davis had done for the company almost twenty years earlier.

Most new vehicles now have power steering, owing to the trends toward front wheel drive, greater vehicle mass, and wider tires, which all increase the required steering effort. Heavier vehicles as common in some countries would be extremely difficult to maneuver at low speeds, while vehicles of lighter weight may not need power assisted steering at all.

Hydraulic systems

A power steering fluid reservoir and pulley driven pump

Most power steering systems work by using a hydraulic system to turn the vehicle's wheels. The hydraulic pressure is usually provided by a gerotor or rotary vane pump driven by the vehicle's engine. A double-acting hydraulic cylinder applies a force to the steering gear, which in turn applies a torque to the steering axis of the roadwheels. The flow to the cylinder is controlled by valves operated by the steering wheel; the more torque the driver applies to the steering wheel and the shaft it is attached to, the more fluid the valves allow through to the cylinder, and so the more force is applied to steer the wheels in the appropriate direction.

One design for measuring the torque applied to the steering wheel is to fix a torsion bar to the end of the steering shaft. As the steering wheel rotates, so does the attached steering shaft, and so does the top end of the attached torsion bar. Since the torsion bar is relatively thin and flexible and the bottom end is not completely free to rotate, the bar will soak up some of the torque; the bottom end will not rotate as far as the top end. The difference in rotation between the top and bottom ends of the torsion bar can be used to control the valve that allows fluid to flow to the cylinder which provides steering assistance; the greater the "twist" of the torsion bar, the more steering assistance will be provided.

Since the pumps employed are of the positive displacement type, the flow rate they deliver is directly proportional to the speed of the engine. This means that at high engine speeds the steering would naturally operate faster than at low engine speeds. Because this would be undesirable, a restricting orifice and flow control valve are used to direct some of the pump's output back to the hydraulic reservoir at high engine speeds. A pressure relief valve is also used to prevent a dangerous build-up of pressure when the hydraulic cylinder's piston reaches the end of the cylinder.

Some modern implementations also include an electronic pressure relief valve which can reduce the hydraulic pressure in the power steering lines as the vehicle's speed increases (this is known as variable assist power steering).

Some heavy machines use hydraulic-only systems where there is no backup if the pump motor fails.

DIRAVI

In the DIRAVI system invented by Citroën, the force turning the wheels comes from the car's high pressure hydraulic system and is always the same no matter what the road speed is. As the steering wheel is turned, the wheels are turned simultaneously to a corresponding angle by a hydraulic piston. In order to give some artificial steering feel, there is a separate hydraulically operated system that tries to turn the steering wheel back to centre position. The amount of pressure applied is proportional to road speed, so that at low speeds the steering is very light, and at high speeds it is very difficult to move more than a small amount from the centre position.

As long as there is pressure in the car's hydraulic system, there is no mechanical connection between the steering wheel and the roadwheels. This system was first introduced in the Citroën SM in 1970, and was known as 'VariPower' in the UK and 'SpeedFeel' in the U.S.

While DIRAVI is not the mechanical template for all modern power steering arrangements, it did innovate the now common benefit of speed sensitive steering. The force of the centering device increases as the car's road speed increases.

In the late 1960s, General Motors offered a variable ratio power steering system as an option on Pontiac and other vehicles.

Electro-hydraulic systems

Electro-hydraulic power steering systems, sometimes abbreviated EHPS, and also sometimes called "hybrid" systems, use the same hydraulic assist technology as standard systems, but the hydraulic pressure is provided by a pump driven by an electric motor instead of being belt-driven by the engine.

In 1965, Ford experimented with a fleet of "wrist-twist instant steering" equipped Mercury Park Lanes that replaced the conventional large steering wheel with two 5-inch (127 mm) rings, a fast 15:1 gear ratio, and an electric hydraulic pump in case the engine stalled.

In 1994 Volkswagen produced the Mark 3 Golf Ecomatic, which utilized an electric pump so that the power steering could operate while the engine had been turned off by the computer to save fuel. Electro-hydraulic systems can be found in some cars by Ford, Volkswagen, Audi, Peugeot, Citroen, SEAT, Skoda, Suzuki, Opel, MINI, Toyota, Honda, and Mazda.

Servotronic

Servotronic offers true speed-dependent power steering, in which the amount of servo assist depends on road speed, and thus provides even more comfort for the driver. The amount of power assist is greatest at low speeds, for example when parking the car. The greater assist makes it easier to maneuver the car. At higher speeds, an electronic sensing system gradually reduces the level of power assist. In this way, the driver can control the car even more precisely than with conventional power steering. Servotronic is used by a number of automakers, including Audi, General Motors, BMW, Volkswagen, Volvo, SEAT and Porsche. Servotronic is a trademark of AM General Corp.

Electric systems

Electric power steering (**EPS** or **EPAS**) is designed to use an electric motor to reduce effort by providing steering assist to the driver of a vehicle. Sensors detect the motion and torque of the steering column, and a computer module applies assistive torque via an electric motor coupled directly to either the steering gear or steering column. This allows varying amounts of assistance to be applied depending on driving conditions. The system allows engineers to tailor steering-gear response to variable-rate and variable-damping suspension systems achieving an ideal blend of ride, handling, and steering for each vehicle. On Fiat group cars the amount of assistance can be regulated using a button named "CITY" that switches between two different assist curves, while most other EPS systems have variable assist, which allows for more assistance as the speed of a vehicle decreases and less assistance from the system during high-speed situations. In the event of component failure, a mechanical linkage such as a rack and pinion serves as a back-up in a manner similar to that of hydraulic systems. Electric power steering should not be confused with drive-by-wire or steer-by-wire systems which use electric motors for steering, but without any mechanical linkage to the steering wheel.

Electric systems have a slight advantage in fuel efficiency because there is no belt-driven hydraulic pump constantly running, whether assistance is required or not, and this is a major reason for their introduction. Another major advantage is the elimination of a belt-driven engine accessory, and several high-pressure hydraulic hoses between the hydraulic pump, mounted on the engine, and the steering gear, mounted on the chassis. This greatly simplifies manufacturing and maintenance. By incorporating electronic stability control electric power steering systems can instantly vary torque assist levels to aid the driver in evasive manoeuvres.

The first electric power steering systems appeared on the Honda NSX in 1990, the FIAT Punto Mk2 in 1999, the Honda S2000 in 1999, and on the BMW Z4 in 2002. Today a number of manufacturers use electric power steering.

Reviews in the automotive press often comment that certain steering systems with electric assist do not have a satisfactory amount of "road feel". Road feel refers to the relationship between the force needed to steer the vehicle and the force that the driver exerts on the steering wheel. Road feel gives the driver the subjective perception that they are engaged in steering the vehicle. The amount of road feel is controlled by the computer module that operates the electric power steering system. In theory, the software should be able to adjust the amount of road feel to satisfy drivers. In practice, it has been difficult to reconcile various design constraints while producing a more pronounced road feel. The same argument has been applied to hydraulic power steering as well.

Variable gear ratios

In 2000, Honda launched the S2000 Type V equipped with the world's first electric power variable gear ratio steering (VGS) system. In 2002, Toyota introduced their own "Variable Gear Ratio Steering (VGRS)" system introduced on the Lexus LX 470 and Landcruiser Cygnus, and also incorporated the electronic stability control system to alter steering gear ratios and steering assist levels. In 2003, BMW introduced their "Active Steering" system on the 5-series.

This system should not be confused with variable assist power steering which varies steering assist torque not steering ratios, nor with systems where the gear ratio is only varied as a function of steering angle.

Hydraulic power steering

A power steering fluid reservoir and pulley driven pump

Hydraulic power steering (HPS) is a hydraulic system for reducing the steering effort on vehicles by using hydraulic pressure to assist in turning the wheels. It is intended to provide for easier driving direction control of the car while preserving "feedback", stability and unambiguity of the trajectory specified.

The steering booster is arranged so that should the booster fail, the steering will continue to work (although the wheel will feel heavier).

Construction

The steering booster consists of the following basic elements:

- Steer torque detector
- Controlled pressure distributor case
- Hydraulic booster pump
- Tank with a working liquid
- Connection hoses

The working liquid, also called "hydraulic fluid" or "oil", is the medium by which pressure is transmitted. Common working liquids are based on mineral oil.

The steering booster works as follows:

The working liquid travels from a tank to the pump inlet opening due to gravity. The liquid travels under pressure from the pump to the distributive gear. The distributive gear has an elastic element, a torsion bar or a spring, which causes the cross-section area of bypass holes (drain ports) to vary in proportion to the effort applied to the steering wheel.

In a neutral position section of the bores passing a liquid in the right and left part of the hydrocylinder is equal to section of bores issued a liquid from them in a tank. The pressures in the right and the left parts of the hydrocylinder are equal too.

When the wheel is turned, because of forces of friction and other forces there is an effort deforming an elastic element, changing the section of bores of the distributive gear and, thereby, pressure in the right and left parts of the hydrocylinder. For pressure restriction in the pump there is a restrictive valve, which is adjusted on different cars in a range from 7 to 13 MPa.

Operation

To avoid dangerous situations under abnormal conditions where the car's steering system suddenly stops working, it is necessary to check the amount of oil in the HPS tank periodically. At an appreciable drop of its level which is not explained by temperature, angle of rotation of wheels, car inclination, etc., it is necessary to check leakproofness of the hydraulic circuit: hoses, places of their inputs etc. To increase the lifetime of the HPS elements and system as a whole, it is recommended to replace the power steering oil completely once every 1-2 years. Manuals of the majority of cars prohibit keeping the wheels in an extreme position for more than 5 seconds as it can lead to the oil heating up to its boiling point, and to the breakdown of the HPS.

Chapter 6

Customised Buses and Environmental Impact-Minimizing Vehicle Tuning

Customised buses

Customised bus in Pakistan

Customised buses are buses that have been modified for decorative purposes. The customisation is unrelated to performing their job or work, usually as public transport buses. Customised buses are also sometimes not used for a job or work, and are decorated as personal projects for exhibition, although this is rare compared to other types of art vehicle such as cars, bikes and customised trucks.

Customisation detail

The customisation usually involves:

- Custom exterior and interior paint schemes, including phrases and proverbs and people, such as religious icons.
- Extra decorative visual elements, such as extra lights and reflectors, flags, banners and bunting or religious symbols and artefacts.
- Modified body parts such more elaborate grilles, wheel arches, exhausts

Incidences of customisation

Slogan on a Malta bus

Pakistan has a long tradition of highly customising buses (and trucks). The Chiva Buses of Colombia are hand-built on truck chassis, used as both public transport and for private hire for parties, including as a novelty attraction in New York City. The jeep derived Jeepney share taxis of the Philippines have grown in capacity to the size of minibuses and are still being built by small scale manufacturers, although are facing calls for their reduction in number and competition with regular public transport. The Colectivo (urban bus) of Argentina, particularly Buenos Aires were historically highly customised, dating back to the 1920s. The practice of customisation continued until the adoption of more modern public transport buses which saw the practice fade out. Historic customised Colectivos are now prized museum exhibits, or have been restored as private vehicles. The island of Malta has had a long tradition of customising their buses used for public transport, due to the variety of models imported, and the small nature of garage facilities. The customisation in Malta is understated compared to other countries. In the 2000s a drive was initiated to update the fleet with more modern buses, but historic examples remain, and the tradition of customisation has continued for the modern models.

Other types of customised buses

Mural on a Chiva bus

Advert buses, party buses, sleeper buses and tour buses are all types of buses that may feature a degree of decorative customisation as part of their primary function, and not just for personalisation.

Environmental impact-minimizing vehicle tuning

Environmental impact-minimizing vehicle tuning refers to the modifying (or tuning) of cars to use less energy.

General tuning

- Hybridization: change to a hybrid electric vehicle. One can use an aftermarket kit for the powertrain or use a hybrid adapter trailer.
- Modifying key engine-selection parameters in the Battery Management System of a hybrid vehicle. Vehicles as mild hybrids have a parameter for the threshold speed on which the vehicle is to switch from electric propulsion to the internal combustion engine. Introducing a higher speed as a parameter can reduce emissions and increase fuel efficiency (although it may increase strain on the battery).
- Pluginization of hybrid or electric vehicles. A plug-in hybrid electric vehicle (PHEV) is a hybrid which has additional battery capacity and the ability to be recharged from an external electrical outlet. A plug-in electric vehicle is basically the same, without an extra internal combustion engine. In addition, modifications are made to the vehicle's control software. The vehicle can be used for short trips of moderate speed without needing the internal combustion engine (ICE) component of the vehicle, thereby saving fuel costs. In this mode of operation the vehicle operates as a pure battery electric vehicle with a weight penalty (the ICE). The long range and additional power of the ICE power train is available when needed.
- Electric vehicle conversion. An electric vehicle conversion is the modification of a conventional internal combustion engine (ICE) driven vehicle to battery electric propulsion, creating a battery electric vehicle. In some cases the vehicle may be built by the converter, or assembled from a kit car. In some countries, the user can choose to buy a converted vehicle of any model in the automaker dealerships only paying the cost of the batteries and motor, with no installation costs (it is called preconversion or previous conversion).
- Modifying the engine to run a alternative fuel. These include natural gas conversion of gasoline-powered cars and Vegetable oil conversion of diesel cars. Cars with Diesel engines can be converted reasonably cheaply and easily to run on 100% vegetable oil. Vegetable oil is often cheaper and cleaner than petrodiesel, but local laws often levy harsh fines to users who fail to pay fuel taxes when acquiring their fuel outside regular distribution channels. Liquid nitrogen, Hydrogen fuel conversions and Ethanol conversions are other alternative fuel conversions that can be done with internal combustion engines. The first two will eliminate all vehicle emissions, while the third one will only slightly decrease emissions. A more complete list can be found at Comparisation of alternative ICE fuels.

- Replacing the internal combustion engine of a hybrid vehicle with a hydrogen fuel cell to make the vehicle completely emissionless; even in recharging mode.
- Adding a hydrogen fuel cell to a battery electric vehicle to increase its driving range.
- Adding more electric batteries to a battery electric vehicle to increase driving range. Besides placing more batteries, this operation often requires additional modification of the Battery Management System.

Chapter 7

Electric Vehicle Conversion

An **electric vehicle conversion** is the modification of a conventional internal combustion engine vehicle (ICEV) to electric propulsion, creating an all-electric or plug-in hybrid electric vehicle.

Elements of a conversion

- Almost *any* vehicle can be converted to electric. Many people prefer to pick a vehicle that is light and aerodynamic in order to maximize distance traveled per battery charge. There must also be adequate room and load capacity for batteries.
- The battery pack, which provides a source of electrical power. The most commonly available and affordable batteries are lead-acid flooded type. Next are the AGM (Absorption Glass Mat) sealed maintenance free batteries, a little more powerful and expensive. Then there are the more exotic batteries like Ni-MH and Li-ion; more difficult to find but light and longer lasting, maintenance free, and much more expensive. The new lithium batteries are showing some promise for EVs in the near future.
- The charger which restores energy to the batteries (which may be mounted within the vehicle or at a special charging station at some fixed location)
- The power controller, which regulates the flow of energy between the battery and the electric motor(s), controlled by an electronic throttle.
- One or more electric motors and their mechanical attachment to the driveline
- Power conductors connecting the battery, controller, and motor(s)
- Accessory equipment to power auxiliary equipment such as power brakes and heating system
- Control circuitry and equipment to allow control and interlocking of the various components
- Instrumentation specific to the operation and maintenance of the conversion

Solar power

Solar cells could be used to power a vehicle converted to electric. However, currently the relatively small power generated by solar cells means that the other components in the system must be special to compensate for this. For example, the body of even a small conventional car converted to electric is still rather too heavy to be able to be matched with an electric system that is solely or primarily charged by solar power. Thus, it is usually more practical to create a solar-powered electric vehicle from scratch or specially made parts.

Conversion process

Most conversions in North America are performed by hobbyists who typically will convert a well used vehicle with a non-functioning engine, since such defective vehicles can be quite inexpensive to purchase. Other hobbyists with larger budgets may prefer to convert a later model vehicle, or a vehicle of a particular type. In some cases the vehicle itself may be built by the converter, or assembled from a kit car.

A two-stage vehicle is a vehicle that has been built by two separate manufacturers. The result is a standard, complete vehicle. In this process, vehicles may be converted by a manufacturer (as was done by Ford Motor Company to create the Ford Ranger EV). Alternatively, in a process known as "third-party (power)trainization", an independent converter will purchase new vehicle gliders (vehicles without a motor or related equipment) and then perform the conversion, to offer a two-stage vehicle.

In some countries, the user can choose to buy a converted vehicle of any model in the automaker dealerships only paying the cost of the batteries and motor, with no installation costs (it is called pre-conversion or previous conversion).

Industry

The electric vehicle conversion industry has grown to include conversion car garages, aftermarket kits and vehicle components.

Vehicle types

Electric bicycle

An electric bicycle is a conventional bicycle that has been fitted with an electric motor. Converting an existing bicycle by retrofitting it with a "conversion kit" is the simplest and least expensive electric vehicle conversion option. Most often electric bicycles or "e-bikes" are powered by rechargeable batteries however some experimental electric bicycles run directly on or recharge their batteries via solar panels, fuel cells, gas generators or other alternative energy sources. Some experimenters have even used super capacitors to store energy. Using an on-board generator may impact the legal jurisdictional definition of an electric bicycle. A few types of electric bicycles are able to re-capture a small amount of energy from braking and can re-charge the batteries while braking or traveling down hills (regenerative braking). With the advent of newer technology further features can be expected.

Some electric bikes have features where the motor can move the bicycle by itself (immediate start) if the rider chooses not to pedal, while others require the rider to pedal at all times (pedal assist). This latter type may in some jurisdictions allow the vehicle to be used on bicycle trails that otherwise prohibit motorized vehicles of any kind. Electric bikes converted with a electric bike conversion system fall under the rules and regulations of the Federal Electric Bicycle Law.

Many battery technologies are available for powering electric bikes. The most common and least expensive battery technology is sealed lead acid but $LiFePO_4$ is fast becoming the battery of choice for the e-bike.

Converting one's bike to electric with a conversion kit is an easy and affordable solution for most people interested in learning more about electric vehicle conversion. E-Bikes are the cleanest, most affordable and most energy efficient form of transportation on the planet.

Electric Two-Wheelers (E-Bikes, Motorcycles and Scooters)

Electric scooter

Custom drag bike

Converted Electric Motorcycle

Low-speed Scooters are not typically suitable for on-the-road use. These may be configured for either standing or sitting use. Some local laws apply bicycle laws to scooters, such as helmet and pedestrian right-of-way considerations.

Economy coupe

This elderly Fiat employs batteries that can be mounted in any position

Owing to its light weight and efficiency, a light vehicle can make an excellent choice, particularly if care is taken in component selection and placement. It is possible to obtain conversion kits for some popular light vehicles, most notably the rear motor, rear drive Volkswagen Beetle, its Type 3 evolution, and its successor, the front motor/drive VW Rabbit.

By converting a light vehicle it is possible to use a smaller motor, which both weighs and costs less than a larger motor. A lighter overall vehicle weight will reduce power consumption in start-and-stop traffic and increase range in many practical driving conditions.

Compact sedan or coupe

A compact sedan may be a better choice than a subcompact owing to better load capacity and more room for battery placement. Some commercial EV Conversions use vehicles in this size range. One example is a 1992 Honda Civic. In this conversion, the back seat was retained, and there is still enough room to sink nine flooded lead-acid batteries low in the trunk where the spare tire was located, as well as another nine batteries under the hood. Another example is a 1987 Mitsubishi Tredia where the rear batteries have been raised above the trunk floorspace, sealed, and externally vented. With suspension modifications, increasing shock length & spring rating, the car must still be below GVWR, even with the driver and passengers. Exceeding the total design weight of the vehicle would be illegal in some states, and might result in cancellation by an insurance company.

There is an effort by several engineers in California to make the Toyota Prius a "Plug-In Hybrid Electric Vehicle," or PHEV, whereby the first 40 miles are driven by all-electric power, then the gas engine comes on to re-charge the batteries, only if the commute is further than 40 mi. If it's less, one can just plug it into the utility grid to re-charge the batteries. The process is done by removing the nickel-metal hydride batteries, and installing different batteries, and a different battery management system.

Since 30 April 2009, the Electric Car Corporation have been selling the Citroën C1 ev'ie, an all-electric conversion from the Citroën C1.

Full-size sedan

Full-size sedans and minivans are generally considered to be poor candidates for EV conversion. As the suspension and tires are already operating close to the maximum permissible, it may be necessary to make substantial modifications in these areas. It may be easier to obtain upgraded suspension components for some smaller vehicles, if these are also typically used for sports racing (particularly autocross). Starting with a heavy vehicle and adding batteries will result in poor performance in acceleration, handling, braking, and economy of operation.

One of possibilities is using the body of Audi's D2 platform A8 (1994–2003) Audi A8 or sports sedan S8 (1998-2003 or older European market models where the German model weights 1730 kg) Audi S8 both of which are all aluminium monocoque "Audi Space Frame" vehicle, which helped to significantly reduce weight without being any less rigid.

Sports car

For a person interested in sports car performance and appearance, the creation of a satisfying conversion will likely lead to a number of difficulties in such details as battery disposition, as such vehicles generally have available space distributed in small volumes around the vehicle. This leads to complexity in securing and wiring batteries. These vehicles can offer stunning performance in the lower speed ranges owing to light weight and rear wheel drive, and may also offer good range due to their superior aerodynamics.

The 1969-1976 Porsche 914 is one of the more successful sports car conversions, as well as being one of the most popular. Once converted, it boasts better performance in range, acceleration and top speed than most other vehicles. Also, its low acquisition costs contributes to its popularity as a conversion candidate. Some manufacturers of conversion kits have made a kit specific to the 914.

Another popular sports car used for conversion is the 1984-1989 Toyota MR2. Reasons for its popularity are low weight before conversion, low cost to purchase the car, and available locations within the car to place the large batteries that most people use (lead-acid and its derivative technologies). The later MR2 body style (Mark 2) does not seem as popular, and as of March 2008, there is only one known conversion.

The Bradley GT II as well as other VW-based kit cars are very popular conversion candidates due to their being inexpensive, extensive support groups as well as their simple sports car design. Availability of conversion kits for these cars are quite prevalent with commercial retail establishments that specialize in EV conversions.

Light truck

Light trucks are especially suitable for hobbyist conversion because it is easy to locate batteries remote from the passenger compartment and there is a good load handling capacity for the use of heavy batteries such as the flooded lead-acid batteries commonly used in golf carts. Light trucks also offer substantial utility in use simply because they are trucks. Even if a portion of the weight capacity is removed by the presence of batteries within or below the cargo bed, much or all of the spatial utility remains. A light truck is highly recommended as a first conversion effort because of the simplicity of component layout. With proper battery placement the stability of a late production truck can be improved over the ICE version. While a number of suitable vehicles are available in pre-2002 models, the modern evolution of this type has become taller, heavier, bulkier and less efficient, and their excessive height makes under-bed battery placement essential to keep the center of gravity low enough for stability on curves.

Other trucks - full size and most SUVs

These are rarely converted due to their excessive weight, and aerodynamic inefficiencies. To make the situation worse, many modern trucks and SUVs continue to get bulkier, heavier, and their high stance means the height of the center of gravity leads to instability while making high speed turns, a distinct disadvantage if there is not enough room between the frame rails to enable low battery mounting. As a direct result, the payload carrying capacity and thus the GVWR of the vehicles goes down. Such a trait is not desirable because it limits the weight of the battery pack that can be carried, limiting the maximum battery-to-vehicle weight ratio that could be achieved for the vehicle when converted to an EV. (Such considerations are important due to price, weight, and performance limitations of current battery technologies.) For a given battery type, reducing the battery-to-vehicle weight ratio always results in reduced vehicle range per charge. However, despite these mostly unavoidable limitations, several SUVs and larger trucks have been successfully converted to electric power by hobbyists. Some examples include the "Gone Postal" van converted to an EV racer by Roderick Wilde and Suckamps EV Racing, the Land Rover EV converted by Wilde Evolutions, and the 1988 Jeep Cherokee EV converted by Nick Viera.

Electric buses

The principal efforts in the development of autonomous electric buses (this is,without trolleys and wires) have involved limited production of very expensive fuel cell vehicles.

The most economically effective development in this area involves the creation of hybrid electric buses (mainly plug-in hybrids), well suited to this application owing to frequent stops and starts and effective energy recovery and release in this cycle.

Another solution is the conversion to battery electric buses that follow the principle of replacing (discharged batteries) instead of recharging.

Racers

Hotrod

While this type of vehicle is usually made to be a "street-legal" performance machine, it may also be developed for occasional use as a drag racing vehicle. The leading vehicle in this field is the "Maniac Mazda" a Mazda RX-7 sports car converted from rotary engine to electric by Roderick Wilde. This vehicle can outrun Dodge Viper and Ferrari sports cars in quarter mile drag races.

Autocross racer

EV's have proven successful in autocross competition. The electric motor's ability to deliver maximum torque at 0 RPM and a comparatively broad torque band provide good throttle response and allow running an autocross without any time lost to shifting gears. The short distance of the typical autocross requires less stored energy than most forms of motorsports. This minimizes electric vehicle's most obvious competitive disadvantage, the weight penalty of batteries compared to gasoline.

Drag racer

Intended only for specialized straight line quarter mile (acceleration) racing this type of vehicle is used only "off road" at specialized "drag strips".

High speed straight line racer

Even more specialized than the drag racer, this is intended to obtain high speeds on long, straight, and flat raceways, such as the dry lake beds found in locations such as the Bonneville Salt Flats.

Closed circuit road racer

Closed Circuit Road racing, particularly any type of endurance racing, is one of the greatest challenges for EV's. Pound per pound, gasoline contains far more energy than even the most advanced of current batteries. An electric vehicle must be heavier or more efficient to run the same distance as its gasoline competitor. Endurance racing strategies include battery packs that can be changed quickly and "Dump charging"

Custom chassis

Suitable for a builder who is capable of constructing a kit car, with good abilities and equipment in machining and welding this can result in a unique vehicle. It is especially suitable for the construction of a lightweight vehicle that can offer exceptional performance. Many VW-based kit car companies have tube chassis ready to start with.

A glider kit includes all components of a vehicle except the power train.

Novelty vehicle

A novelty vehicle or an electric powered art car may not be suitable for on road use. Applications include electric vehicle show demonstrations, parades, parade floats, float towing, and eclectic off-road gatherings such as Burning Man. This vehicle is ideal for the beach (where not prohibited) and to promote tourist places but will usually require trailering to its operating site.

At the 2005 Stanford University EV Gathering



Above: Bob Schneeveis demonstrates his *Silver Sofa*.

Registration of converted and newly constructed vehicles

United States

The ease of registration will vary by state. Some states require safety inspections, usually to ensure body integrity in areas subject to severe corrosion from winter road de-icing materials. In any case, for general registration all functional safety equipment should be operating - turn signals, brake lights, headlights, horn, etc. The windshield should have no running cracks (small stone chips and "stars" may be acceptable if not in the driver's principal line of vision). If the vehicle has been reconstructed from a salvage vehicle (a vehicle whose registration has been forfeited) inspection may be more severe to ensure compliance and the legitimacy of sources of salvage components by presentation of proper purchase receipts.

Registration procedures will vary by state and will usually be more difficult (even bizarre) in states with strict emissions requirements (even though a plug-in only conversion will be a zero emission vehicle). Arguing with DMV staff is typically futile in all jurisdictions, but there may be appeal procedures available but whose availability may not be openly publicized.

On the other hand, changing the registration allows a conversion to qualify for tax incentives available in some states, such as Oregon, for either the vehicle, the charging system, or both.

California (US) conversion registration and taxation

Registration of a converted existing, or newly self constructed electric vehicle in California is difficult.

This falls into two categories ; First, if the vehicle is built from new frame components and possibly some salvage parts, (*i.e.*, it has never been a previously titled motorcar previously, but it has brakes or axles that were obtained used/rebuilt.) In California if you "Create' a car from scratch and want to register and title it with DMV , you need to go through the "Specially Constructed Vehicle Emission Control Program or SPCNS for short, this is also called California "SB100" program. SPCNS Sequence Numbers are limited at 500 units per calendar year.

The SPCNS / SB100 Program is intended / meant for emission control for home built kit cars or hot rods. as of November 2009, California DMV has no pathway for a home builder to create a electric car without subscribing to the current SPCNS program, which was originally meant for historic replicas and gasoline powered cars.

Limitation: California SB100/SPCNS is limited to 500 cars per year. All 500 "sequence numbers" are consumed within minutes on the first DMV business day of the calendar year. SPCNS registration requires a significant paper trail on all frame/body/components, this is to assure stolen parts are not used in construction. Additionally, since registration fees and vehicle sales tax are generated from these figures, their requirement aids in revenue collection for each SPCNS number issued.

OFF-ROAD vehicles; "Kei car"-class trucks, four wheel sport "dirt" vehicles, and other utility vehicles imported and sold for off-road use only; The electric conversion of a vehicle that was previously not certified for "On-Road" does not enable it to be registered for "On-Road" use with the conversion to electric power only. An example; certain subcompacts cannot qualify for registration except if a custom body or frame is installed to have the vehicle confirm to "On-Road" brake/light/safety standards.

As all originally ICE street-legal automobiles and light trucks built after 1975 must pass a smog test (including a "visual inspection"), a conversion of such a late model vehicle *must* be registered as an *electric powered only* vehicle and thus exempt. Otherwise, it would fail the required smog test, not for producing pollution, but for being altered from its original configuration and so failing the *visual inspection* portion of the test. Since 1975 and earlier vehicles are not currently tested for any smog compliance, it would be possible to convert them to electric power with little or no paperwork/certification issues.

It is no more simple if the vehicle is registered with current tags in California and may even be more difficult. Under new 2008 regulations for converted ICE vehicles a multi-step process is required. First, an appointment is made by telephone with a "Smog Referee". A meeting with the vehicle to be registered will typically be at a local community college with an extensive automotive shop program. The referee will inspect and certify that the vehicle is both smog exempt and that it qualifies for an "E" power code (electric-only). The next step requires real-time coordination between a cooperative clerk at the local California Department of Motor Vehicles (DMV) office and an appropriate clerk at the Sacramento office. (These procedures are in place to inhibit fraudulent registration of ICE vehicles as Electric in order to avoid smog inspections.) If the computer terminals are not operated in a coordinated manner the registration propulsion code will default to "Q" (hybrid vehicle) which is *not* exempt from smog inspection and the conversion will always fail such an inspection. Unfortunately, once the computer has defaulted to the "Q" code it is necessary to re-engage the Smog Referee to obtain a new prospective "E" code. The ability to successfully register as an electric vehicle is highly dependent upon the cooperation of the staff at the local office, their experience with registering electric vehicles, their ability to coordinate with Sacramento, and their interest in assisting you. Some offices will be much more accommodating than others. Multiple trips to the DMV office and the Referee are typically required.

Since no fuel or recharging taxes are collected the revenue that would otherwise be lost to the state is made up for with a substantial weight fee specific to electric vehicles *registered for commercial use* (no weight charges are added for noncommercial vehicles). While light ICE vehicles are taxed on a refined and progressive grading scheme, electric vehicles with commercial licenses are grouped into only a few broad categories, with the result that even a modest and lightweight commercially registered EV will pay the same tax as will a much heaver (up to 6000 lbs) EV. If an open-bed pickup truck (as opposed to a panel truck) is converted, the only way to register it as a non-commercial vehicle (and so avoid the weight fees) is to *permanently* install a camper shell (not a bed cover), which need not project above the truck cab nor include any other "camping" equipment. (This can be inconvenient if access to an in-bed battery box is required.) In California, one advantage of a commercial license is the ability to park in yellow zones, but only for short term pick-up and delivery.

Spain

In Spain, the conversion (called transformation) is regulated by the Royal Decree 736/1988, of 8 of July, *por el que se regula la tramitación de las reformas de importancia de vehículos de carretera*.

Chapter 8

Cutdown, Car Tuning and Conversion Van

Cutdown

A **cutdown** (sometimes known as a *skelly*) is a customised scooter (usually an Italian Vespa or Lambretta) with parts of the bodywork removed or cut away. Cutdowns were popular amongst skinheads and scooterboys during the mod revival of the 1970s and 1980s. While the style-obsessed British mod youth subculture of the 1960s prized the glamorous, metropolitan image of scooters, many skinheads and scooterboys viewed their bikes as simply a form of transportation.

This "naked" Lambretta has been cut down and customized

While some scooter enthusiasts have focused on the stripped-down look, with just a bare frame and visible motor and mechanical parts, some scooterboys put back almost as much hardware as they had taken off, by adding customized chrome-plated accessories and racks.

Modifications

Many cutdowns have unneeded parts removed to improve power to weight ratio. Typically, the fenders, leg shields, floors, tail section and cowls are removed. Cutting away body parts is the easiest with Lambretta scooters, because they are built on a tubular frame, which means that the body parts do not have a structural role. Vespa scooters, on the other hand, are usually built with a unibody design, so the body panels give the bike its structure. This means that when Vespas are cut down, they cannot be made as bare-bones as a Lambretta. The body panels of a Vespa are modified by slimming them down or giving them a different shape, in such a way that the structural soundness of the bike is not compromised.

Cutdowns are often tuned – much like a four-wheeled hot rod – by overboring the cylinders to increase engine power or adding performance exhausts, modified carburettors, or aftermarket shock absorbers. Some enthusiasts replace the standard drum front brakes with hydraulic disc brakes or add water-cooled radiators. Lambretta owners may replace existing parts with a Nikasil plated aluminium barrel with radical porting, large Dell'Orto or Mikuni carburettors and bespoke (custom-made) expansion chambers, hydraulic clutches, and modern low-profile tyres. Some scooterists use aluminum Fabrizi racing barrels, because they use a rotary induction mechanism. Stock gas tanks may be replaced with YSR tanks, which put the weight of the fuel further forward. Some riders install a windshield to reduce wind resistance and enable higher speeds. To reduce weight, some scooterists use lighter-weight aftermarket parts, such as SIP carbon sports seats and other parts made from carbon fibre, carbon kevlar and fibreglass.

Some cutdowns have been used for drag racing. At scooter races, cutdowns often race in a separate category called the "specials", which is for cutdown and heavily modified racing scooters. The other scooter race categories include stock races with relatively unmodified larger scooters (152 to 250 cc) and "small frame" races for scooters with 136 cc or smaller engines. For races, scooters usually have to have accessories removed, such as center and side stands, mirrors, turn signals that stick out, and luggage racks. Scooter races often disallow performance-enhancing fuel additives such as octane booster.

Related scooter types

A cutdown scooter resembles a **"naked scooter"**, which is a scooter designed without panels covering the engine and with little or no bodywork. The difference between the two types is that while a cutdown scooter started as a regular scooter with body panels and bodywork, before it was customized, a "naked scooter" is designed and manufactured as a "bare-bones" vehicle. In the 1960s, Lambretta models A through D were in this category. In the 1990s, Italjet produced a stripped-down scooter called the Dragster. In the 2000s Honda produced the Ruckus, which had the motor mounted in a skeleton-style metal frame.

The Honda Ruckus uses a skeleton-style frame without body paneling

Another scooter type which is related to cutdowns is the **"chopper"**, which is a cutdown scooter with extra-long front forks. These bikes are often made with Lambrettas, because when the bodywork is removed from their tubular frame, they resemble mini Harley-Davidson motorcycles. **"Rats"** are cutdowns which are made by putting together old parts to create a rough-looking, unpainted bike. In contrast to many other scooter enthusiasts, "rat" builders view blemishes and unrepaired dents as attractive. The "rat" approach to scooter customizing is similar to the rat rod style of hot rodding, in which old cars often have original paint with rust patches, or even just bare rusty metal. Major scooter rallies which give prizes to scooters sometimes put "chopper" and "rat" scooters in a separate category from the rest of the cutdowns.

Car tuning

A tuned Toyota Mark II

Car tuning is both an industry and a hobby, in which an automobile, motor bike, scooter or moped is modified in order to improve its performance, handling and presentation and improve the owner's driving style. As most vehicles leave the factory set up for average driver expectations and average conditions, tuning has become a way to personalize the characteristics of the vehicle to the owner's preference. For example, they may be altered to provide better fuel economy, produce more power at high RPM or the ride comfort may be sacrificed to provide better handling.

Car tuning is related to auto racing, although most performance cars never compete. Rather they are built for the pleasure of owning and driving such a vehicle. Another major facet of tuning includes performance modification to the car exterior. This includes changing the aerodynamic characteristics of the vehicle via side skirts, front and rear bumpers, adding spoilers, splitters, air vents and light weight wheels.

Areas of modification

Audio

Is a term used to describe the sound or video system fitted in the vehicle. A stock audio system refers to one that was specified by the manufacturer when the vehicle was built in the factory. A custom audio installation can involve anything from the upgrade of the radio to a full-blown customization based around the audio equipment. Events are held where entrants compete for the loudest, highest quality reception or most innovative sound systems.

Interior tuning

Interior tuning is a term used for modifying the interior of a car. for example; removing the back seats to make room for a sound system, or taking out the front seats and replacing them with racing seats - commonly known as bucket seats.

Another recent form of interior tuning is the replacement of the OEM Shift Knob with an aftermarket version such as a weighted shift knob for cosmetic and/or for performance purposes.

Engine tuning

Engine tuning as of lately has been marketed as the replacement of basic engine components with aftermarket versions that perform the same functions as those replaced while promising an increase in power output. Car tuners usually install new turbochargers, modify the car's engine cooling unit, and replace the air filters; but they could also install a more powerful engine on the cars they modify.

For example a tuner could modify the engine control unit to gain more power. Another example is the modification and/or replacement of the OEM manual transmission stick shift (also known as a gear stick) with an optimized aftermarket design known as a short shifter. For further "fine" tuning, the driver could fit a Weighted Gear Knob.

Today’s car and light truck engines are fully electronically controlled. That makes it very easy to enhance the performance of the engine through “Chip-Tuning”. What that means, is a completely electronically tuning of the engine by modifying the programming of the computer chips, which control the engine management. Chip tuning is applicable for fuel as well as for diesel engines provided the engine is equipped with an electronic motor management. That said, engines with turbochargers, compressors or superchargers are the most effective to tune.

Suspension tuning

Suspension tuning involves modifying the springs, shock absorbers, swaybars, and other related components of a vehicle. Shorter springs offer greater stiffness, a lower center of gravity, and a lowered look. Stiffer shock absorbers improve the dynamic weight shifting during cornering and normally have shorter internals to stop them from bottoming out when shorter springs are used. Stiffer sway bars reduce body roll during cornering, thus improving the grip that the inside tires have on the surface; this improves handling response. Other components that are sometimes added are strut bars, which improve the body stiffness and help better maintain the proper suspension geometry during cornering. On some cars certain braces, anti-roll bars, etc., can be retrofitted to lower-spec cars from sports models.

For offroad vehicles, the emphasis is on lengthening the suspension travel and larger tires to increase ground clearance.

Lowriders with hydraulic/pneumatic suspensions use another unique kind of suspension tuning in which the height of each individual wheel can be rapidly adjusted by system of rams, even to the extent that it is possible to "bounce" the wheels completely clear of the ground.

Body tuning

Body tuning involves adding or modifying spoilers and a body kit. Sometimes this is done to improve the aerodynamic performance of a vehicle, as in the case of some wings or bumper canards, or, to lighten the vehicle through replacing bodywork components such as hoods and rear view mirrors with components made from lighter composites such as CFRP. Cornering speeds and adhesion can be improved through the generation of downforce, often at the expense of increased drag.

More often however, these modifications are done mainly to improve a vehicle's appearance, as in the case of non-functioning scoops, spoilers, wide arches or any aesthetic modification which offers no benefit to performance. Very rarely does an after market spoiler or body kit improve performance, the majority add weight and increase the drag coefficient of the vehicle and thus reduce its overall performance.

Increasing the wheel track width through spacers and wide body kits enhance the cars cornering ability. Lowering the center of gravity is another aim of body tuning dealt with via suspension modifications. However, similar to the addition of non-functioning body kits and spoilers, oftentimes suspension tuners unfamiliar with spring dynamics will cut stock springs, producing a soft, bouncy ride. It is also common to lower the car too far, past the optimal center of gravity, purely for appearance.

Competition cars usually have either light weight windows or no windows. Glass is relatively heavy and auto glass is usually thicker than bodywork. Replacing it with plastic saves high up weight, improving almost all performance qualities, at the expense of greatly reduced scratch resistance and therefore service life.

Tires

Since tires have large effects on a car's behavior and are replaced periodically, choosing tires different from the original ones is a very cost effective way to personalize an automobile. Choices include tires for various weather and road conditions, different sizes and various compromises between cost, grip, service life, rolling resistance, handling and ride comfort.

Detuning

Detuning involves returning a modified car to its original factory status. It is akin to automotive restoration. The term *detuning* can also refer to the reduction or decrease of performance in a particular area of tuning. An example of this could be where the engine is "detuned" to allow increased traction on a day where the track grip is not sufficient to handle the increased power of the tuned engine.

Terms

"Streeted" or "Tuner Cars" are Japanese vehicles, such as a Honda Integra DC5, Toyota Supra, Nissan Skyline, Mazda RX-7, Subaru Impreza, and the Mitsubishi Lancer Evolution series. These cars are most commonly modified with the more expensive mods available. The most popular modifications include suspension upgrades, exhaust systems, and turbos.

Legal requirements

Many countries have legal requirements in regard to what car owners can and can't do in relation to vehicle modifications. For example, all vehicles in Victoria, Australia, must conform to construction standards to ensure vehicles provide drivers and passengers with a maximum level of safety. There are also restrictions for P Plate drivers which can prevent young drivers from driving modified vehicles.

In the United Kingdom and the Netherlands it is illegal for any car to have blue lights as they are used by the emergency vehicles.

In Scotland and Denmark, it is illegal for any car to have neon underlights on a car as it distracts other drivers. In the Netherlands neon is allowed under the car but only when the car is on display, if the car is on a public road the lights have to be switched off. Many police officers in the U.K are unsure on the exact legislation with regards to under body neons. Most say as long as the bulb is not visible itself then this is legal.

Recently, Belgium issued a new law which describes that bodykit parts need to be approved for safety issues.

Sanctioning organizations

Many organizations involved in competitive motorsports establish safety guidelines that far exceed legal requirements placed on civilian street legal vehicles. The NHRA, IHRA and SOLO programs all require that vehicles pass inspection to ensure that all regulations are being complied with.

Clubs

A big part of car modifications are car clubs or groups. Many are specific to particular car manufacturers. Clubs often attend national shows all over the country. There are thought to be over 100 car clubs in the UK.

Conversion van

Converted 2009 GMC Savana

A **Conversion van** Is a full-size cargo van that is sent to third-party companies to be outfitted with various luxuries for road trips and camping.

History

Converted 1988-1996 Chevrolet Sport Van

Conversion vans came into style during the 1970s and 1980s. Early conversions were simply vans with seats put in them, often with murals painted along the sides. Although many were used by rock bands and the conversion van developed something of a "bad boy" image, most were used for basic everyday transport.

After the mid 80's, luxurious interiors featuring thickly padded seats, wood trim and luxury lighting began to appear in conversion vans as families and retirees started using them for road trips and camping. At the same time, both the federal government and vehicle manufacturers began efforts to exert some degree of control on the van conversion industry, demanding that certain safety guidelines be adhered to. The price of conversion vans also started to increase as things such as sleeping accommodations, cooking utilities, televisions and other items were added to the conversion vans. The higher pricing and smaller market segment meant a resulting decrease in sales. Also, DVD and flat screen technology meant that many automobiles now have features once exclusive to conversion vans. At the same time, the price of gas was also increasing, leading still more people away from these large cargo vans, whose V-8 engines and poor aerodynamics resulted in poor gas mileage. Finally, the growing demand for minivans and SUVs siphoned off even more potential customers. Despite these setbacks though, as the economy boomed in the 1990s, conversion vans sales began to improve, with almost 200,000 units sold in 1994 alone. As of 2007, about 20,000 conversion vans are being sold each year, with most being sold for family transport.

Top Types

The most basic difference in conversion vans is the type of "top".

Low Tops- these are the older type of vans. Low top vans retain the factory roof on the van. These vans are better aerodynamically but have less room inside. During the '80's, these vans fell out of favor because TV's, VCR's, and video games that became very popular were also very bulky. With the development of integrated DVD's and flat screen monitors, these van's have recovered somewhat, but they continue to run a distant second to high topped vans.

High Tops- These vans have the original factory roof cut away and a fiberglass "high top" or "elk roof" or "high-raised roof" added. This has become the signature feature of a conversion van. A high top allows occupants to stand in the van without bending over. This has led to its inclusion on disability vans because a wheelchair occupant can be lifted into the van without ducking. It has also become a requirement on campervans. The high top also allows for vastly more storage. Also, the early TV's and VCR's (discontinued) and now it installs DVD's could be mounted in the ceiling, so they did not inhibit movement and leg room in the van. The first high tops started not much higher than the factory roof, then raised aft of the driver's seat with two skylights mounted in this section, typically flanking a TV antenna. This soon fell out of favor due to leaking and light hitting the occupants. High tops began to raise at a gentle angle with a steeply raked center spine section. The center section house an internally mounted antenna and allowed for larger 13" TV's. Modern vans no longer have to worry about room for a TV and high tops have a much more integrated look.

Conversion types

There are several different types of conversions aside of the usual passenger-van-like conversion:

1. **Travel Van-** These are the standard conversion vans and the only ones offered with low tops as well as high tops. A typical travel van will accommodate 7 passengers on one rear bench, and four captain's chairs. Often, the rear bench electronically folds flat into a bed. These vans normally have large windows with shades, storage cabinets, and a TV. Originally, TV's were small DC conversion models with antennas. These TV's were bulky (Especially in low tops, were they had to be mounted on the floor. and not very useful due to poor signals. In the '80's, VCR's and later DVD players were added greatly improving the usefulness of the TV. Finally, flat screen monitors have eliminated the need for special cabinetry to hold the TV. High end stereo systems and other electronics have become typical. Most accommodate multiple game systems.

2. **Disability Vans -** The van has any or all of the following structural modifications that enable a person in a wheelchair to use the van: Raised roof to allow proper clearance through the door, Raised roof to allow adequate head clearance, lowered or dropped floor to allow adequate head clearance. These changes are made necessary because a person

sitting in a wheelchair will almost always sit higher than a person sitting in the van's OEM seats. In all cases a platform lift is added to either the rear doors or passenger side doors to enable the person in a wheelchair to enter/exit the van. A lowered floor modification can be done just in the cargo area to save money whereas a full lowered floor is one in which both the cargo area and driver/passenger area are lowered. Standard lowered floor conversions are 6" and 9".

3. **Office Vans** Also known as "LandJets", are built like a small office in the back, with a desk and chair bolted to the floor, an electrical outlet in the office area (for computer, etc.), and usually 1 or 2 seats in the back for passengers. These are most popular for traveling salesmen and TV camera crews.

4. **Motorhomes** "Class B" **campervan** are built on a full size cargo van that is lengthened a couple of feet. Lengths range from 17–20 feet. "Class C" mini motorhomes have the back completely taken out of the van (known as a cutaway), and have it replaced with a larger back that offers more space than Class B's. Lengths range from 18–30 feet. These vans have more features that enable camping, such as a toilet, fridge, microwave, sink, side sofa, popup canvas top that allows standing up, and sometimes a stove.

Vans used in conversions

Current

Conversion vans are originally bare, windowless full-size 1/2 ton or 3/4 ton cargo vans such as the Chevrolet Express/GMC Savana, the Dodge Sprinter, and the Ford E-Series. Recently, the Ford Transit Connect has been the subject of conversions. The microvan offers a vehicle with improved gas mileage and marks the first time since companies ceased conversions of Chrysler minivans that a car-based van has been used in conversions. The **Conversion Van Marketing Association** (CVMA) is a partnership between General Motors and 7 conversion van manufacturers. Exclusive partnership means members of the CVMA are the only manufacturers authorized by GM to build Chevrolet or GMC conversion vans.

Former

Vans used for conversions in the past that are no longer in production are the Chevrolet Van/GMC Vandura (1970–1996), the Chevrolet Astro/GMC Safari (1985–2005), the Dodge Ram Van (1981–2003), Chrysler minivans, and the Volkswagen Eurovan (1992–2004).

Conversion Minivans

- Chevrolet Astro
- Chrysler Town & Country
- Chrysler Voyager (not available)
- Dodge Caravan

- Ford Windstar
- GMC Safari
- Plymouth Voyager (discontinued)
- Volkswagen Eurovan

Conversion Full-Size vans

- Chevrolet Express
- Chevrolet Van
- Dodge Ram Van
- Dodge Sprinter
- Ford E-Series
- Ford Transit Connect
- Freightliner Sprinter
- GMC Savana
- GMC Vandura

Chapter 9

Chopper (Motorcycle)

A Replica chopper of one used in the film *Easy Rider*

A **chopper** is a type of motorcycle that was either modified from an original motorcycle design ("chopped") or built from scratch to have an authentic appearance. The main features of a chopper that make it stand out are its longer frame design accompanied by a stretch front end (or rake). To achieve a longer front end, while the frame is being designed, the fabricator will tilt the neck of the frame at less of an incline and install a longer fork. Another unique aspect of a chopper design is that there is usually no rear suspension meaning the frame of the motorcycle will extend from the neck (or front of the frame) all the way to the rear wheel. This can make handling the motorcycle more challenging and the ride a bit more "bumpy". These attributes may seem radical to some but is necessary for the look that is desired. One look that is becoming more popular with chopper designs is a low frame to ground clearance or a low-rider look. Well known examples of chopper designs are the customized Harley-Davidsons seen in the 1969 film *Easy Rider*.

History

An example of a stock 1940's Indian Scout that came with very large fenders.

Before there were choppers, there was the bobber, meaning a motorcycle that had been "bobbed," or relieved of excess weight by removing parts, particularly the fenders, with the intent of making it lighter and thus faster, or at least making it look better in the eyes of a rider seeking a more minimalist ride. An early example of a bobber is the 1940

Indian Sport Scout "Bob-Job" which toured in the 1998 *The Art of the Motorcycle* exhibition. Indian Scouts and Chiefs of the time came with extravagantly large, heavily valenced fenders, nearly reaching the center of the wheel on the luxurious 1941 Indian Series 441 while racing bikes had tiny fenders or none at all. The large and well-appointed bikes exemplified the "dresser" motorcycle aesthetic and providing a counterpoint to the minimalist bobber, and cafe racers. Choppers would grow into and explore the dimensions of the space between the stripped-down bobbers and weighed-down dressers.

In the post-World War II United States, servicemen returning home from the war started removing all parts deemed too big, heavy, ugly or not absolutely essential to the basic function of the motorcycle, such as fenders, turn indicators, and even front brakes. The large, spring-suspended saddles were also removed in order to sit as low as possible on the motorcycle's frame. These machines were lightened to improve performance for dirt-track racing and mud racing.

Forward-mounted foot pegs replaced the standard large 'floorboard' foot rests. Also, the standard larger front tire, headlight and fuel tank were replaced with much smaller ones. Many choppers were painted preferably all in either flat black or in shiny metallic “metal flake” colors. Also common were many chromed parts (either one-off fabricated replacements or manually chromed stock parts). According to the taste and purse of the owner, “chop shops” would build high handle bars, or later “Big Daddy” Roth Wild Child’s designed stretched, narrowed, and raked front forks. Shops also custom built exhaust pipes and many of the “after market kits“ followed in the late 1960s into the 1970s. Laws required (and in many locales still do) a retention fixture for the passenger, so vertical backrests called sissy bars were a popular installation, often sticking up higher than the rider's head.

While the decreased weight and lower seat position improved handling and performance, the main reason to build such a chopper was to show off and provoke others by riding a machine that was stripped and almost *nude* compared to the softer-styled stock Harley-Davidsons, let alone the oversized automobiles of that time.

Traditional choppers

In the United States servicemen returning from World War II were looking for a thrill. Many veterans had been trained to work on automobiles and motorcycles and were looking to add a little excitement to their post-war lives with their newly acquired mechanical skills. Motorcycles and Hot Rods were the perfect hobby for them. Motorcyclists bought up surplus military bikes and removed all the unnecessary parts such as windshields and saddlebags to minimise weight. Rear fenders were "bobbed" or shortened just enough to handle a passenger and keep the rain and mud coming off the rear, and sometimes removed the mirrors, or replaced them with tiny ones, such as the type used by dentists in their work.

This type of home customization led to the rise of the "bobber". Then in the 60s, motorcyclists found that a longer front end allowed the bike to run smoother at faster speeds. The degree of neck rake and length of front end was modified on these bikes with this in mind. The Girder and Springer front ends were the most popular forks for extending in this fashion, although this does make the bike harder to handle at slower speeds. Nevertheless, some choppers have extremely long forks; as one biker said, "You couldn't turn very good but you sure looked good doing it."

To build or chop a traditional chopper an unmodified factory bike is used (usually a rigid Harley Davidson) and everything unnecessary to either move or stop is stripped or chopped off. Then the engine and transmission are removed and the frame is cut up and welded back together to make it lower and lighter. Performance parts are added or modified to increase speed.

Today's chopper era

Orange County Choppers Firebike

Jesse G. James riding a West Coast Choppers, chopper

Santee "Hardcore II" Custom rigid chopper

Choppers have enjoyed a large following. Companies like Jesse G. James' West Coast Choppers have been successful in producing expensive traditional chopper-style bikes and a wide range of chopper-themed brands of merchandise such as clothing, automobile accessories and stickers.

A distinction should be noted between true chopper (or chopper-style) motorcycles, and custom motorcycles, or 'custom cruisers'. Despite the name, a large percentage of the motorcycles produced by popular companies such as Orange County Choppers, Indian Larry, Falcon Motorcycles, and Von Dutch Kustom Cycles are better described as 'custom' bikes rather than choppers.

A distinction should also be made between choppers and bobbers. While both tried to improve performance by removing any part that did not make the motorcycle perform better, they differed in an important way: bobbers kept the original *factory* frame, while choppers have a modified form of the factory frame.

When individuals were stripping their stock motorcycles and bobbing their fenders, the term "bobber" was born. When individuals started cutting (or chopping) and welding their frames thereby repositioning/restyling them, the term "chopper" was born. Chopping was the next phase in the evolution that followed dirt track bobbing.

While people assume that the *chopper* style motorcycles were built purely for aesthetics, there is a real performance advantage to the *raked* front end on these choppers. These motorcycles have a much more stable feel at high speeds and in a straight line than motorcycles with original *factory* front suspensions. However, like any other modification, there is a downside: the raked front end feels heavier and less responsive at slow speeds or in curves and turns. This is due to the longer trail measurement associated with increased rake.

Changing the rake and trail of a motorcycle design requires modification of the design itself. This is a job that requires in-depth input from a motorcycle designer who is experienced with such design changes. A triple tree can be raked, or designed so the lower tree sticks out further than the upper tree, thus increasing the rake of the forks in relation to the steering head rake. What this does, is position the axle closer to the frame rake measurement line, or shortening the trail. Thus, when adding raked trees to a raked frame (which sports a longer trail), the trail is shortened to a more manageable level. Adding raked trees to a frame with short rake and trail can be hazardous, as shortening an already short trail measurement can lead to an unstable situation as speed increases.

Despite the personalized nature of choppers, and the wide availability of alternative designs, chopper builders have overwhelmingly chosen fat rear tires, a rigid-looking frame (even for a softail), and an original or replica air-cooled, pushrod v-twin engine. In the UK, due to the cost and lack of availability of the v-twin engine, many chose to use British engines from bikes such as Triumph or BSA; lately as availability has increased, Japanese engines have seen more use. Some people feel that the variety of engines and other components used more recently (especially on bikes built outside of the US) is diluting the signature appearance of the chopper style. Modern bobber builders tend to distinguish themselves from chopper builders with bikes styled before the chopper era. Modern bobber builder Jan Bachleda in Colorado builds custom choppers and bobbers using Triumph engines and frames from the 1970s and earlier. The look, though chopped, is distinctly modern and low. Today's custom choppers are usually seen as center pieces at bike night events around the United States.

The United States of America, where most custom choppers reside, is one of the few countries in the world that allow custom-built choppers to be licensed for highway use. Many of these types of choppers are regarded as dangerous to operate and don't follow basic design geometry and lack many safety features in their construction.

Choppers in Australia

Australian Design Rules (ADRs) limit frame modifications and fork extensions to 6 inches (150 mm). The most restrictive rule allows a maximum distance of 550 mm from the front axle horizontally back to the steering head. Noise restrictions and handlebar dimensions are also regulated. However, in some states ADRs do not apply to pre-1977 motorcycles, so some older, more radical choppers are still seen on Australian roads.

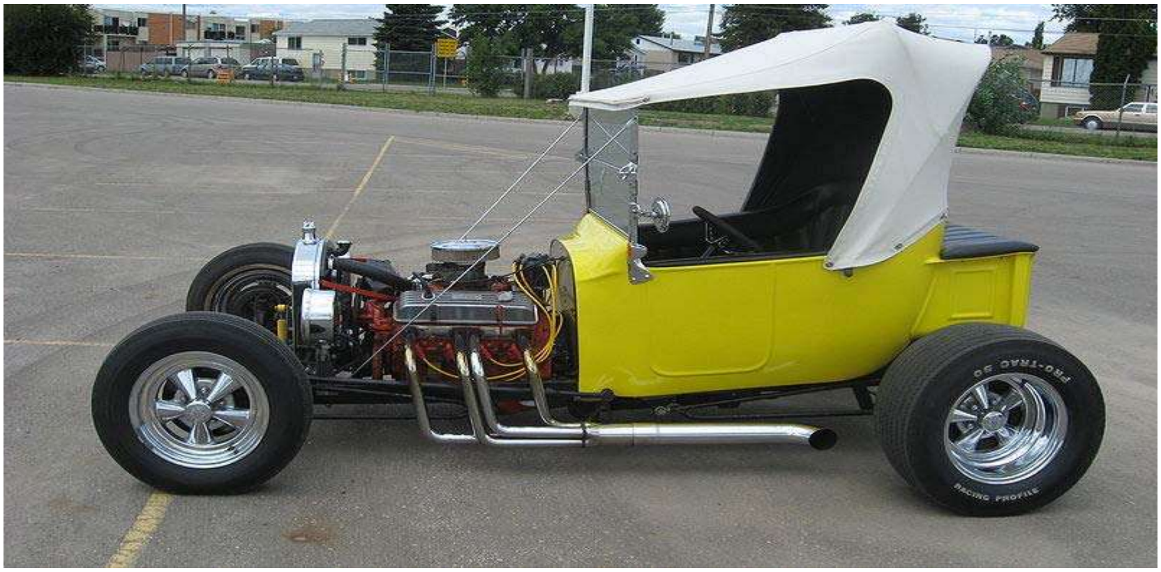
Chapter 10

Custom Car

'32 3-window with a classic-style flame job and Moon tank, very reminiscent of Chapouris' *California Kid*.

Custom '51 Merc with red "ghost flames" and appletons

"Rat rodded" Deuce coupe with Edelbrock head and chrome carb hats on late-model flatty.



The iconic "T-bucket" custom. Exposed engine is virtually mandatory, as are flat windshield, headers, and open pipes. Soft top (shown) is optional. Also features chrome five-spokes, dropped tube axle, transverse front leaf spring, front disc brakes, open-face aircleaner, Weiand valve covers, and single 4-barrel (probably a QJ).

Front suspension of yellow lowboy Deuce roadster. Note color-matched springs on coilover shocks, tube axle, vented disc brakes.

'41 Willys. Note the non-stock one-piece windshield

'55-7 Chevy with fuzzy dice

'Big Daddy' Roth 'bloodshot eyeball' shift knob, a 1960s craze.

'28 A roadster with Kelsey-Hayes wire wheels

A **custom car** is a passenger vehicle that has been modified in either of the following two ways. First, a custom car may be altered to improve its performance, often by altering or replacing the engine and transmission. Second, a custom car may be a personal "styling" statement by the re-styler/re-builder, making the car look "unique" and unlike any car that might have been factory finished. Customs are distinct from hot rods; exactly where the difference lies has been the subject of debate among customizers and rodders for decades.

History

A development of hot rodding, the change in name corresponded to the change in the design of the cars being modified. The first hot rods were pre-World War II cars, with running boards and simple fenders over the wheels. Early model cars (1929 to 1934) were modified by removing the running boards and either removing the fenders entirely or replacing them with very light "cycle fenders". Later models usually had "fender skirts" installed on the rear fenders. Many cars were "hopped up" with engine modifications such as adding additional carburetors, high compression heads and dual exhausts. "Engine swaps" were done, the object of which was to put the most powerful engine in the lightest possible frame and body combination. The suspension was usually altered. Initially this involved lowering the rear end as much as possible with the use of "lowering blocks" on the rear springs. Later cars were given a "rake job" either adding a "dropped" front axle or heating front coil springs to make the front end of the car much lower than the rear. Much later some hot rods and custom cars swapped the old solid rear axle for an independent rear axle, often from Jaguar. Only rarely was the grille of one make of car replaced by another; one exception was the 1937 Buick grille, often used on a Ford. (In the 1950s and 1960s, the grille swap of choice was the 1953 De Soto.) The original hot rods were plainly painted like the Model A Fords from which they had been built up, and only slowly begun to take on colors, and eventually fancy orange-yellow flamed hoods or "candy-like" deep acrylic finishes in the various colors.

With the change in automobile design to encase the wheels in fenders and to extend the hood to the full width of the car, the former practices were no longer possible. In addition, there was tremendous automotive advertising and subsequent public interest in the new models in the 1950s. Hence custom cars came into existence, swapping headlamp rings, grilles, bumpers, chrome side strips, and tail lights, as well as "frenching" and "tunnelling" head- and taillights. The bodies of the cars were changed by cutting through the sheet metal, removing bits to make the car lower, welding it back together, and adding a lot of lead to make the resulting form smooth (hence the term "lead sled"; lead has been replaced by Bondo). By this means, "chopping" made the roof lower; "sectioning" made the body thinner from top to bottom. "Channeling" was cutting notches in the floorpan where the body touches the frame to lower the whole body. Fins were often added from other cars, or made up from sheet steel. In the custom car culture, someone who merely changed the appearance without also substantially improving the performance was looked down upon.

Features

Paint

Paint was an important concern. Once bodywork was done, the cars were painted unusual colors. Transparent but wildly-colored candy-apple paint, applied atop a metallic undercoat, and metalflake paint, with aluminum glitter within candy-apple paint, appeared in the 1960s. These took many coats to produce a brilliant effect — which in hot climates had a tendency to flake off. This process and style of paint job was invented by Joe Bailon, a customizer from Northern California.

Customizers also continued the habit of adding decorative paint after the main coat was finished, of flames extending rearward from the front wheels, scallops, and hand-painted pinstripes of a contrasting color. The base color, most often a single coat, would be expected to be of a simpler paint. **Flame jobs** later spread to the hood, encompassing the entire front end, and have progressed from traditional reds and yellows to blues and greens and body-color "ghost" flames. One particular style of flames, called "crab claw flames", which is still prevalent today, is attributed to Dean Jeffries.

Painting has become such a part of the custom car scene that now in many custom car competitions, awards for custom paint are as highly sought after as awards for the cars themselves.

Engine swaps

Engine swaps have always been commonplace. Once, the flathead, or "flatty", was the preference, supplanted by the early hemi in the 1950s and 1960s. By the 1970s, the small-block Chevy was the most common option, and since the 1980s, the 350 cu in (5.7 l) Chevy has been almost ubiquitous. The flatheads and early hemis have not entirely disappeared, but ready availability, ease of maintenance, and low cost of parts makes the SB Chevy the most frequent engine of choice.

Once customizing post-war cars caught on, some of the practices were extended to pre-war cars, which would have been called fendered rods, with more body work done on them. An alternate rule for disambiguation developed: hot rods had the engine behind the front suspension, while customs had the engine over the front suspension. The clearest example of this is Fords prior to 1949 had Henry Ford's old transverse front suspension, while 1949 models had a more modern suspension with the engine moved forward. However, an American Museum has what could be the first true custom, 1932 Clobes .

With the coming of the muscle car, and further to the high-performance luxury car, customization declined. One place where it persisted was the U.S. Southwest, where lowriders were built similar in concept to the earlier customs, but of post-1950s cars.

As the supply of usable antique steel bodies has dried up, companies such Westcott's, Harwood, Gibbon Fiberglass and Speedway Motors have begun to fabricate new fiberglass copies, while Classic Manufacturing and Supply, for one example, has been making a variety of new steel bodies since the 1970s. California's "junker" (or "crusher") law, which pays a nominal sum to take "gross polluters" off the road, has been criticized by enthusiasts (and by SEMA) for accelerating this trend.

Starting in the 1950s, it became popular among customizers to display their vehicles at drive-in restaurants. Among the largest and longest lasting was Johnie's Broiler in Downey, California. The practice continues today, especially in Southern California.

Customizers

Examples of notable customizers include George Barris, Bill Cushenberry, the Alexander Brothers, the "legendary" Gil Ayala, Darryl Starbird, Roy Brizio, Troy Trepanier (of Rad Rides by Troy), Boyd Coddington, Harry Westergaard, Dave Stuckey, Dean Jeffries, "Posie", Ron Clark and Bob Kaiser (of Clarkaiser Customs), Joe Bailon (inventor of candy apple paint), Gene Winfield, Joe Wilhelm, "Magoo", Chip Foose, and Pete Chapouris. Others, such as Von Dutch, are best known as custom painters. Several customizers have become famous beyond the automobile community, including Barris, Jeffries, and Coddington, thanks to their proximity to Hollywood; Barris designed TV's Batmobile, while Chapouris built the flamed '34 three-window coupé in the eponymous telefilm "The California Kid". Another Barris creation, *Ala Kart* (a '29 Ford Model A roadster pickup), made numerous appearances in film (usually in the background of diner scenes and such), after taking two AMBR wins in a row.

Awards

The highest award for customizers is the AMBR (America's Most Beautiful Roadster) trophy, presented annually at the Grand National Roadster Show since 1948 (also known within the customizer community as the Oakland Roadster Show until it was moved to Southern California in 2003). This competition has produced famous, and radical, customs.

Another is the Ridler Award, presented at the Detroit Autorama since 1964 in honor of show promoter Don Ridler. With one of the most unusual of car show entry requirements, winners of the prestigious Ridler Award are selected as the most outstanding from among cars being shown for the first time. This prompts builders of many high-end roadsters to first enter the Autorama first and then the Grand National show in order to have the chance to win top honors at both shows. Few cars and owners can claim this achievement.

Chapter 11

Custom Wheel and Rat Rod

Custom wheel

The term **custom wheel** refers to the wheels of a vehicle which have either been modified from the vehicle manufacturer's standard or have replaced the manufacturer's standard.

Uses

Custom wheels are one of the most common ways in which automobile enthusiasts customize their vehicles. Competition-oriented enthusiasts typically switch to lighter, stronger, or larger wheels, while appearance-oriented enthusiasts more often choose larger and more visually distinctive wheels, inspired by those seen in hip-hop videos.

The most-desirable characteristics of custom wheels vary with owner's goals:

Activity	Primary characteristics considered
Automobile racing	Weight
Drag racing	Width (for traction)
Rally	Strength
Street driving	Visual appeal, weight (gas mileage)
Touring car racing and autocrossing	Weight, width (less tire flex for better cornering performance)
Multi-purpose	Strength, visual appeal, weight, width, achieved by maintaining multiple sets of wheels

Physics

At some point, the performance advantage of larger wheels and reduced-profile tires meets the performance disadvantage of increased inertia and increased unsprung weight. This point varies depending on the vehicle, style of wheel, and driving style; however, most vehicles do not see a performance increase when rims are more than two sizes larger than original-equipment specifications. Appearance-oriented enthusiasts may feel that decreased performance and an increased risk of road damage from the use of oversized rims is a worthwhile price to pay for the look they want.

Theft

Newer aftermarket rims may be worth thousands of dollars. Owners use special lug nuts, called wheel locks, to secure them, although it renders the vehicle difficult to service, and there are doubts as to how well the locks thwart determined thieves.

Rat rod

An example of a Rat Rod

A **rat rod** is a style of hot rod or custom car that, in most cases, imitates (or exaggerates) the early hot rods of the 40s, 50s, and 60s. It is not to be confused with the somewhat closely related "traditional" hot rod, which is an accurate re-creation or period-correct restoration of a hot rod from the same era.

Most rat rods appear "unfinished" (whether they actually are or not), with just the bare essentials to be driven.

The rat rod is the visualization of the idea of function over form. Rat rods are meant to be driven, not shown off. Sometimes the customization will include using spare parts, or parts from another car altogether.

Definition

Originally a counter-reaction to the traditional hot rod, a label recently applied to undriven cars and super high priced "customs", the rat rod's beginning was a throwback to the hot rods of the earlier days of hot-rodding, built to the best of the owner's abilities and meant to be driven. Rat rods are meant to loosely imitate in form and function the "traditional" hot rods of the era. Biker, greaser, rockabilly, and punk cultures are often credited as influences that shaped rat rodding.

The typical rat rod is an early 1930s through 1950s coupe or roadster. Early (pre-World War II) vehicles often have their fenders, hoods, running boards, and bumpers removed. The bodies are frequently channeled over the frame, and sectioned, or the roofs chopped for a lower profile. Later post-war vehicles are rarely constructed without fenders and are often customized in the fashion of Kustoms, leadsleds, and lowriders. Maltese crosses, skulls, and other accessories are often added. Chopped tops, shaved trim, grills, tail lights, and other miscellaneous body parts are swapped between makes and models. Most, if not all, of the work and engineering is done by the owner of the vehicle.

Recently, the term "rat rod" (or rat car, as modern cars are not actually hot rods like the name suggests) has been used to describe almost any vehicle that appears unfinished or is built simply to be driven.

General

Chassis

Frames from older cars or light trucks are preferred for the chassis, because they provide a sturdy base for subsequent alterations. Older cars in poor condition are often advertised as candidates for rat rod conversions. In some cases the owner will design and build the frame himself.

Paint and finish

Typical "rough" finish of Rat Rods

Many rat rods appear unfinished, with primer-only paint jobs. Satin or matte black and other flat colors are also common. Other finishes may include “natural patina” (the original paint with rust and blemishes intact), a patchwork of original paint and primer, or bare metal with no finish at all in rusty or oiled varieties, honoring the anti-restoration slogan that "it's only original once". Many rat rods also have free hand pinstriping done by the owners with a pinstriping brush. Contrary to tastes of many car builders, rust is often acceptable and appreciated by a rat rodder.

Interior

Interiors of rat rods vary from fully finished to a spartan, bare bones form. Mexican blankets and bomber seats form the basis of many rat rod interiors. Most are designed to be functional without many comforts although this will vary with the owner’s taste.

Drive train

Though a variety of engines may be used, the most common to be found in a rat rod are flathead V8's, early Chrysler Hemi engines, or more modern small block V8's from any manufacturer, especially Chevrolet. It is not uncommon to see straight-8s straight-6s, straight-4s, V6s, or even diesel engines. These engines may exhibit varying displacements and modifications.

Most rat rods are rear wheel drive, with an open driveline. The rear-ends are typically passenger vehicle pieces, as are the transmissions. The Ford Banjo rear-end is popular, as is the "Quickchange" type as used in many early hot rods.

Suspension

A beam axle is commonly accepted as the only type of front suspension that will look right when exposed without fenders on a vehicle with open front suspension. Independent front suspension is discouraged, and most rat rods use a 1928-1948 Ford I-beam axle with a transverse leaf spring. Although any solid axle is acceptable, the Ford axle is preferred due to the availability of spare parts.

Springs vary from transverse, parallel and coil setups in the front and rear. Parallel is not seen as frequently as the more common single-spring transverse setup, though both are used commonly. Coil springs are often deemed unsightly without fenders, but are still occasionally seen. Rat rods also will often have airbag suspension, which allows the driver to raise and lower the car.

Origins

The December 1972 issue of *Rod & Custom Magazine* was dedicated to the "beater", a low-budget alternative to the over-polished, slickly-painted, customized early car. The beater could easily be considered a progenitor of the rat rod with its cheap upholstery, primer instead of paint, and lack of chrome or polished metals. However, owners of these beaters often had a high-dollar machine sitting in their garage.

As with many cultural terms, there are disputes over the origin of the term "rat rod". Some say it first appeared in an article written in *Hot Rod Magazine* by Gray Baskerville about cars that still sported a coat of primer. Some claim that the first rat rod was owned by artist Robert Williams who had a '32 Ford Roadster that was painted in primer. *Hot Rod* magazine has since verified this. Although the term likely started out as derogatory or pejorative (and is still used in this way by many), members of the subcultures that build and enjoy these cars have adopted the term in a positive light.