Rolling Stock Technologies & Locomotive Components

Paul Coronado

Raegan Freitas

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Table of Contents

Chapter 1

Locomotive

Three body styles of diesel locomotive: cab unit, hood unit and box cab. These locomotives are operated by Pacific National in Australia.

R class steam locomotive number R707 as operated by the Victorian Railways of Australia.

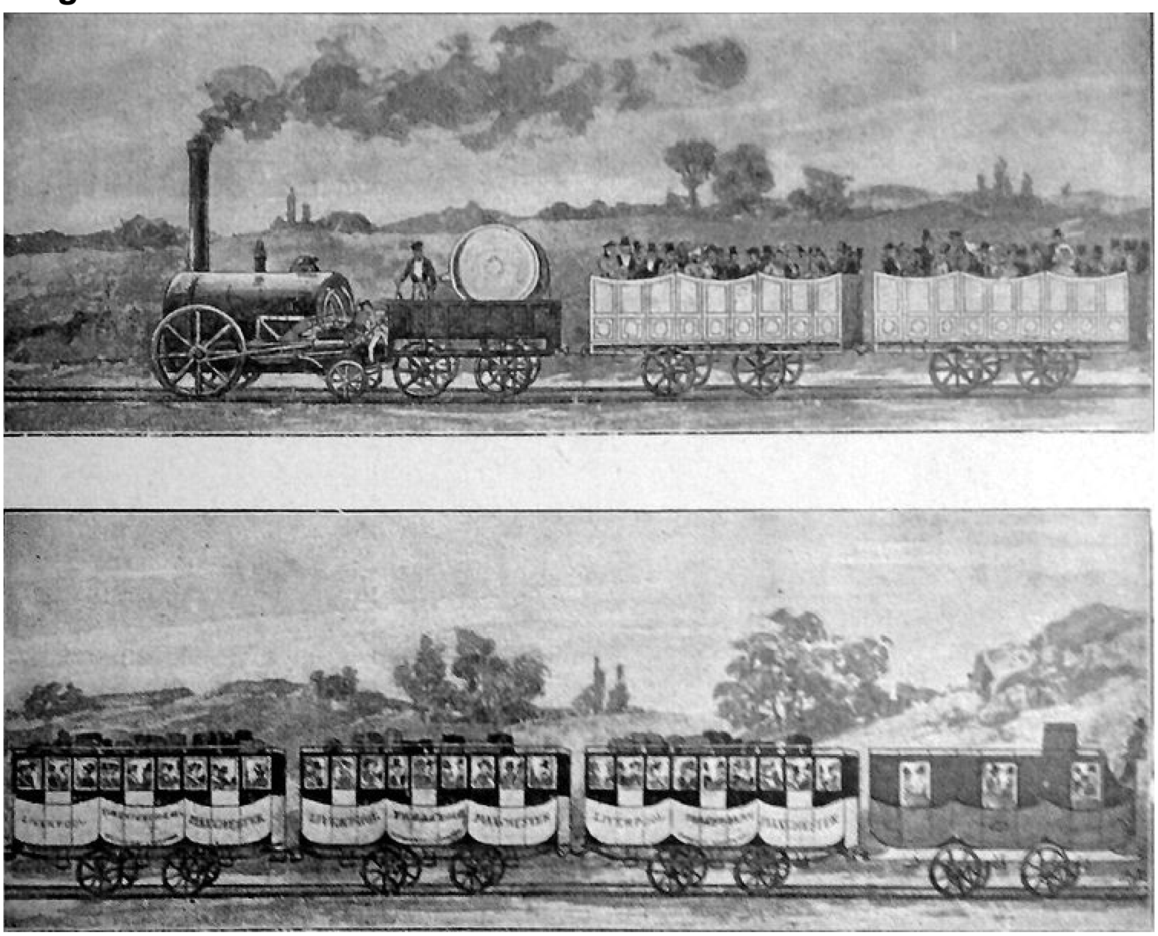
A Green Cargo RC 4 class electric locomotive repainted in its original livery for the Swedish 150-year railway anniversary in 2006.

A **locomotive** is a railway vehicle that provides the motive power for a train. The word originates from the Latin *loco* – "from a place", ablative of *locus*, "place" + Medieval Latin *motivus*, "causing motion", and is a shortened form of the term *locomotive engine*, first used in the early 19th century to distinguish between mobile and stationary steam engines.

A locomotive has no payload capacity of its own, and its sole purpose is to move the train along the tracks. In contrast, some trains have self-propelled payload-carrying vehicles. These are not normally considered locomotives, and may be referred to as multiple units, motor coaches or railcars. The use of these self-propelled vehicles is increasingly common for passenger trains, but rare for freight. Vehicles which provide motive power to haul an unpowered train, but are not generally considered locomotives because they have payload space or are rarely detached from their trains, are known as power cars.

Traditionally, locomotives pull trains from the front. Increasingly common is push-pull operation, where a locomotive pulls the train in one direction and pushes it in the other, and can be controlled from a control cab at the other end of the train.

Origins



First passenger railway, L&MR

The first successful locomotives were built by Cornish inventor Richard Trevithick. In 1804 his unnamed steam locomotive hauled a train along the tramway of the Penydarren ironworks, near Merthyr Tydfil in Wales. Although the locomotive hauled a train of 10 tons of iron and 70 passengers in five wagons over nine miles (14 km), it was too heavy for the cast iron rails used at the time. The locomotive only ran three trips before it was abandoned. Trevithick built a series of locomotives after the Penydarren experiment, including one which ran at a colliery in Tyneside in northern England, where it was seen by the young George Stephenson.

The first commercially successful steam locomotive was Matthew Murray's rack locomotive, *Salamanca*, built for the narrow gauge Middleton Railway in 1812. This was followed in 1813 by the *Puffing Billy* built by Christopher Blackett and William Hedley for the Wylam Colliery Railway, the first successful locomotive running by adhesion only. Puffing Billy is now on display in the Science Museum in London, the oldest locomotive in existence.

In 1814 George Stephenson, inspired by the early locomotives of Trevithick and Hedley persuaded the manager of the Killingworth colliery where he worked to allow him to build a steam-powered machine. He built the *Blücher*, one of the first successful flanged-wheel adhesion locomotives. Stephenson played a pivotal role in the development and widespread adoption of steam locomotives. His designs improved on the work of the pioneers. In 1825 he built the *Locomotion* for the Stockton and Darlington Railway, north east England, which became the first public steam railway. In 1829 he built *The Rocket* which was entered in and won the Rainhill Trials. This success led to Stephenson establishing his company as the pre-eminent builder of steam locomotives used on railways in the United Kingdom, the United States and much of Europe. The first inter city passenger railway, Liverpool and Manchester Railway, opened in 1830, making exclusive use of steam power for both passenger and freight trains.

Locomotives vs. multiple units

Advantages of locomotives

An early design of electric locomotive showing the steeplecab arrangement: North Eastern Railway No.1, England from 1905

There are many reasons why the motive power for trains has been traditionally isolated in a locomotive, rather than in self-propelled vehicles.

Ease
: Should the locomotive fail, it is easy to replace it with another. Failure or maintenance of the motive power unit does not require taking the entire train out of service.

Maximum utilization of power cars
: Idle trains waste costly motive power resources. Separate locomotives enable costly motive power assets to be moved around as needed.

Flexibility
: Large locomotives can be substituted for small locomotives where the grades are steeper and more power is needed. A 'passenger' locomotive can also be used for freight duties if needed, and vice versa.

Obsolescence cycles

Separating the motive power from payload-hauling cars enables one to be replaced without affecting the other. At times locomotives have become obsolete when their cars were not, and vice versa.

Safety

In case of an accident, the locomotive may act as buffer zone for the rest of the train. If an obstacle is encountered on the line, the heavier mass of a locomotive is less likely to be deviated from its normal course. Also it may be safer in the event of fire especially with diesel locomotives.

Noise

A single source of tractive power, which means only motors in one place, means that the train will be quieter than with multiple unit operation, where one or more motors are located under every carriage. The noise problem is particularly present in diesel multiple units.

Advantages of multiple units

There are several advantages of multiple unit (MU) trains compared to locomotives.

Energy efficiency

Multiple units are more energy efficient than locomotive-hauled trains and more nimble, especially on grades, as much more of the train's weight (sometimes all of it) is placed on driven wheels, rather than suffer the dead weight of unpowered coaches.

No need to turn locomotive

Many multiple units have cabs at both ends , the train may be reversed without uncoupling/re-coupling the locomotive, giving quicker turnaround times, reducing crew costs, and enhancing safety. In practice, the development of driving van trailers and cab cars has removed the need for locomotives to run-around, giving easy bi-directional working and removing this MU advantage.

Reliability

As multiple unit trains have multiple engines, the failure of one engine does not prevent the train from continuing its journey. A locomotive drawn passenger train typically only has one power unit, meaning the failure of this causes the train to be disabled. However, some locomotive hauled passenger trains may utilize more than one locomotive, as do many locomotive hauled freight trains, and so are able to continue at reduced speed after the failure of one locomotive.

Safety

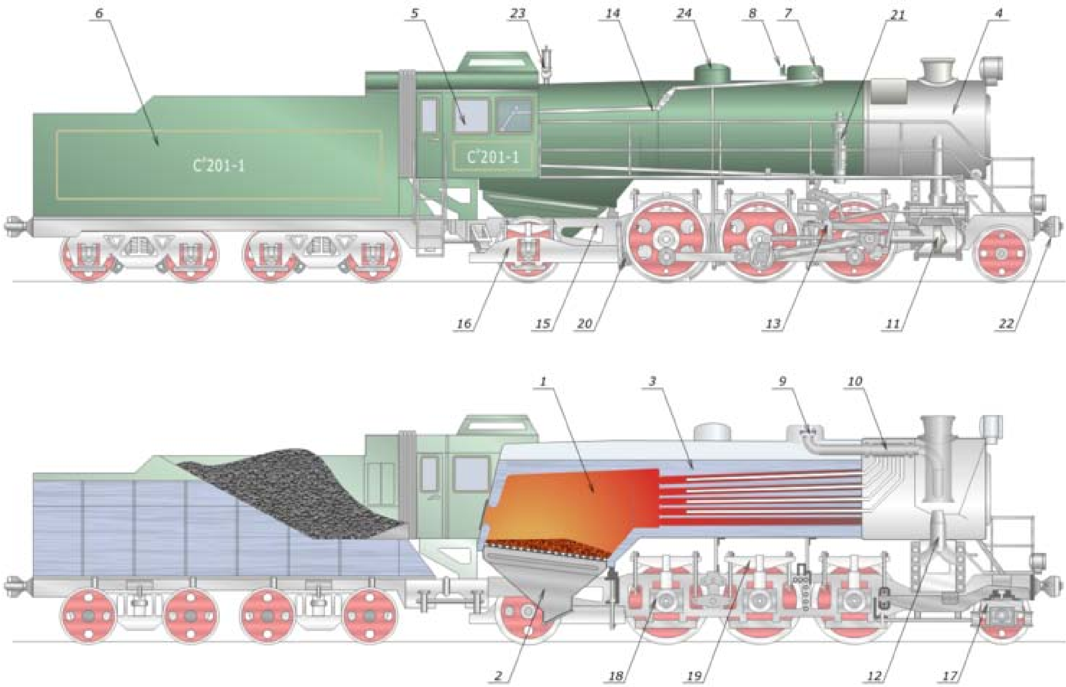
Multiple units normally have completely independent braking systems on all cars, meaning the failure of the brakes on one car does not prevent the brakes throughout the train from operating safely.

Locomotive classifications

Motive power

Locomotives may generate their power from fuel (wood, coal, petroleum or natural gas), or they may take power from an outside source of electricity. It is common to classify locomotives by their source of energy. The common ones include:

Steam



The main components of a steam locomotive

A steam locomotive at the Gare du Nord, Paris, 1930

Locomotive 030-219 of Renfe in Miranda de Ebro, Spain

In the 19th century the first railway locomotives were powered by steam, usually generated by burning coal. Because steam locomotives included one or more steam engines, they are sometimes referred to as "steam engines". The steam locomotive remained by far the most common type of locomotive until after World War II.

The first steam locomotive was built by Richard Trevithick; it first ran on 21 February 1804, although it was some years before steam locomotive design became economically practical.. The first commercial use of a steam locomotive was *The Salamanca* on the narrow gauge Middleton Railway in Leeds in 1812. The locomotive *Fairy Queen*, built in 1855 runs between Delhi and Alwar in India and is the oldest steam locomotive in regular (albeit tourist-only) service in the world, and the oldest steam locomotive operating on a mainline.

The all-time speed record for steam trains is held by an LNER Class A4 4-6-2 Pacific locomotive of the LNER in the United Kingdom, number 4468 *Mallard*, which pulling six carriages (plus a dynamometer car) reached 126 mph (203 km/h) on a slight downhill gradient down Stoke Bank on 3 July 1938. Aerodynamic passenger locomotives in Germany attained speeds very close to this and due to the difficulties of adequately balancing and lubricating the running gear, this is generally thought to be close to the practicable limit for a direct-coupled steam locomotive.

Before the middle of the 20th century, electric and diesel-electric locomotives began replacing steam locomotives. Steam locomotives are less efficient than their more modern diesel and electric counterparts and require much greater manpower to operate and service. British Rail figures showed the cost of crewing and fuelling a steam locomotive was some two and a half times that of diesel power, and the daily mileage achievable was far lower. As labour costs rose, particularly after the second world war, non-steam technologies became much more cost-efficient. By the end of the 1960s-1970s, most western countries had completely replaced steam locomotives in passenger service. Freight locomotives generally were replaced later. Other designs, such as locomotives powered by gas turbines, have been experimented with, but have seen little use, mainly due to high fuel costs.

By the end of the 20th century, almost the only steam power still in regular use in North America and Western European countries was on heritage railways largely aimed at tourists and/or railroad hobbyists, known as 'railfans' or 'railway enthusiasts', although some narrow gauge lines in Germany which form part of the public transport system, running to all-year-round timetables retain steam for all or part of their motive power. Steam locomotives remained in commercial use in parts of Mexico into the late 1970s. Steam locomotives were in regular use until 2004 in the People's Republic of China, where coal is a much more abundant resource than petroleum for diesel fuel. India switched over from steam-powered trains to electric and diesel-powered trains in the 1980s, except heritage trains. In some mountainous and high altitude rail lines, steam engines remain in use because they are less affected by reduced air pressure than diesel engines. Steam locomotives remained in routine passenger use in South Africa until the late 1990s, but are now reserved to tourist trains. In Zimbabwe steam locomotives are still used on shunting duties around Bulawayo and on some regular freight services.

As of 2006 DLM AG (Switzerland) continues to manufacture new steam locomotives.

Gasoline

Gasoline locomotives have been produced since the early 1900s.

Diesel

The EMD F40PH uses a Diesel-electric transmission designed by Electro-Motive Diesel.

Experimental diesel-powered locomotives were first built just after World War I. In the 1940s, they began to displace steam power on American railroads. Following the end of World War II, diesel power began to appear on railroads in many countries. In many countries the significantly better economics of diesel operation triggered a dash to diesel power, a process known as Dieselization. By the late 1960s, few major railroads in North America, Europe and Oceania continued to operate steam locomotives, although significant numbers still existed outside these areas.

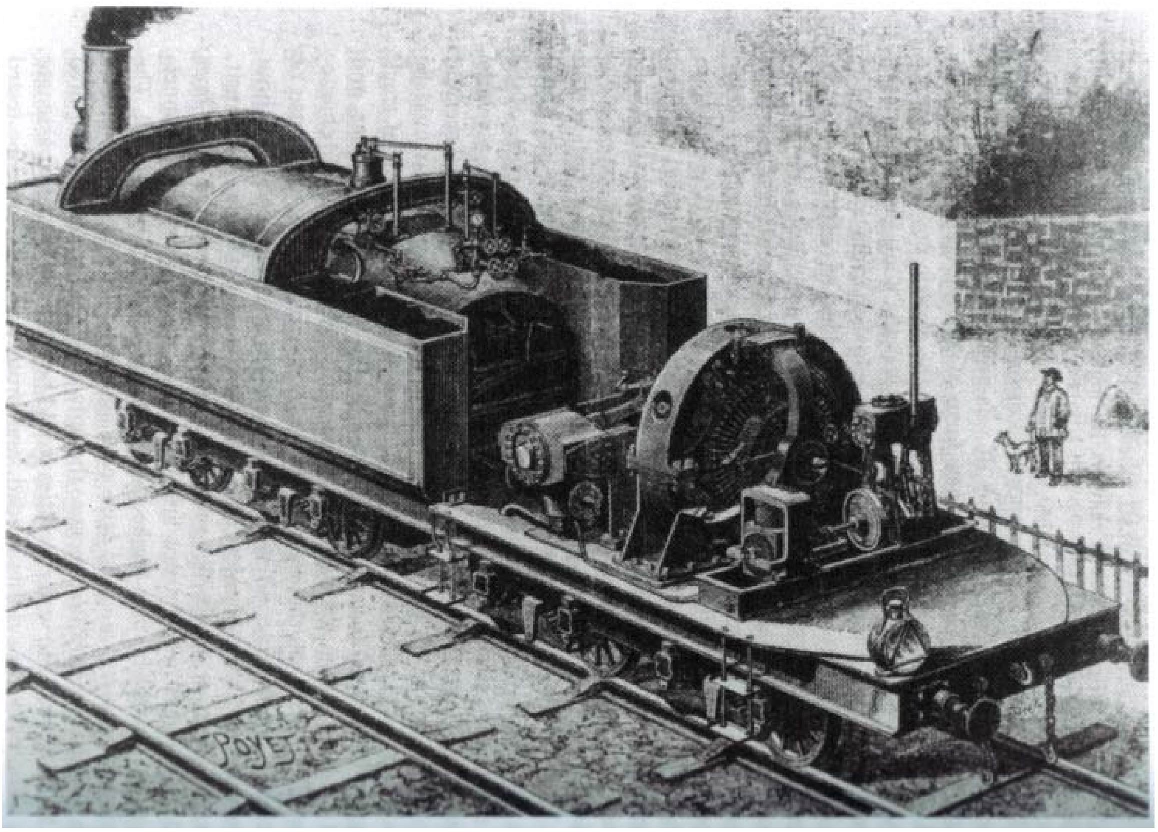
As is the case with any vehicle powered by an internal combustion engine, diesel locomotives require some type of power transmission system to couple the output of the prime mover to the driving wheels. In the early days of diesel railroad propulsion development, electric, hydraulic and mechanical power transmission systems were all employed with varying degrees of success. Of the three, electric transmission has proved to be most popular, and although diesel-hydraulic locomotives have certain advantages and are continuously used in some European countries, most modern Diesel-powered locomotives are diesel-electric.

Diesel locomotives require considerably less maintenance than steam, with a corresponding reduction in the number of personnel needed to keep the fleet in service.

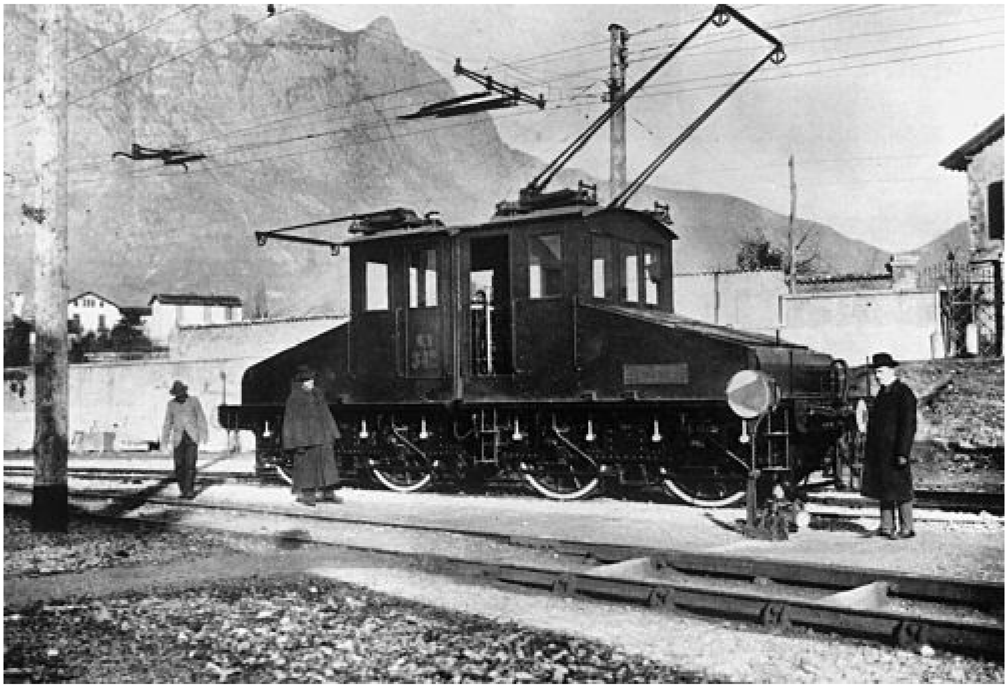
The best steam locomotives spent an average of three to five days per month in the shop for routine maintenance and running repairs. Heavy overhauls were frequent, often involving removal of the boiler from the frame for major repairs. In contrast, a typical diesel locomotive requires no more than eight to ten hours of maintenance per month. and may run for many years between heavy overhauls.

Diesel units are not as polluting as steam power; modern units produce low levels of exhaust emissions. Diesel-electric locomotives are often fitted with "dynamic brakes" that use the traction motors as electrical generators during braking to assist in controlling the speed of a train on a descending grade. This technology is similar to regenerative braking used in hybrid cars, the key difference being that dynamic braking does not store the generated power, instead routing it to resistors where it is converted into waste heat.

Electric



The "Fusée Electrique" of 1893, cab removed. Compounded pistons drove a Gramme-style dynamo powering electric motors on all axles. The small engine, right, was the exciter for the dynamo windings.



AC locomotive in Valtellina (1898-1902). Power supply: 3-phase 15 Hz AC, 3000V, (AC motor 70km/h). It was designed by Kálmán Kandó in Ganz Company, Hungary.

In 1893 in Paris Charles Brown assisted Jean Heilmann in evaluating AC and DC transmission systems for "Fusée Electrique", a steam locomotive with electric transmission, and using this knowledge he designed a three-phase AC electric locomotive for Oerlikon, Zurich. Brown (by then in partnership with Walter Boveri) put these into service on the first electrified main line, the Burgdorf—Thun line, Switzerland, in 1899. Each thirty-tonne locomotive had two 150 hp (110 kW) motors.

In 1894, a Hungarian engineer Kálmán Kandó developed high-voltage three phase alternating current motors and generators for electric locomotives. His work on railway electrification was done at the Ganz electric works in Budapest. The first installation was on the Valtellina line, Italy, in 1902. Kandó was the first who recognised that an electric train system can only be successful if it can use the electricity from public networks. After realising that, he also provided the means to build such a rail network by inventing a rotary phase converter suitable for locomotive usage.

The electric locomotive is supplied externally with electric power, either through an overhead pickup or through a third rail. While the capital cost of electrifying track is high, electric trains and locomotives are capable of higher performance and lower operational costs than steam or diesel power. Electric locomotives, because they tend to be less technically complex than diesel-electric locomotives, are both easier and cheaper to maintain and have extremely long working lives, usually 40 to 50 years – there are many examples of electric locomotives operating for more than half a century with minimal overhaul, and it is not unusual for electric locomotives to be operating close to their centenary. The Finnish State Railroad is planning to phase out the Soviet-manufactured VR Class Sr1 engines, operative since 1973, in 2024, at which time they will have been over fifty years in line service.

A French TGV holds the world speed record for the fastest wheeled train, having reached 574.8 km/h (357.2 mph) on 3 April 2007.

Some electric locomotives can also operate off battery power to enable short journeys or shunting on non-electrified lines or yards. Battery-powered locomotives are used in mines and other underground locations where diesel fumes or smoke would endanger crews, and where external electricity supplies cannot be used due to the danger of sparks igniting flammable gas. Battery locomotives are also used on many underground railways for maintenance operations, as they are required when operating in areas where the electricity supply has been temporarily disconnected.

Hybrids

The main reason why hybrid locomotives have been invented is because this eliminates the need for a mechanical transmission. Otherwise, a gearbox would be needed which is large, complicated and inefficient. A hybrid locomotive allows the internal combustion engine to run at a constant speed, turning an electrical generator which in turn powers an electrical engine.

Several types of internal combustion engine (ICE)-electric hybrids exist, including gasoline-electric, diesel-electric, and Gas turbine-electric

In addition, there are also fuel-cell-electric locomotives, forming a category on their own.

Besides hybrid locomotives which use only a fuelled power source (i.e. internal combustion engine, and a electrical engine , there are also hybrids that use a fuelled power source, battery and electrical engine. Here, the battery acts as a temporary energy store, allowing e.g. the implementation of regenerative braking and switching off the hydrocarbon engine when idling or stationary (as used in automobiles such as the Toyota Prius). Steam-diesel hybrid locomotives have been tried in Britain, Russia and Italy but with only limited success.

Gas turbine-electric

UP 68, one of Union Pacific's 4,500 hp 'veranda' turbines. From the Don Ross Collection

A gas turbine-electric locomotive, or GTEL, is a locomotive that uses a gas turbine to drive an electrical generator or alternator. The electric current thus produced is used to power traction motors. This type of locomotive was first experimented with in 1920 but reached its peak in the 1950s to 1960s. The turbine (similar to a turboshaft engine) drives an output shaft, which drives the alternator via a system of gears.

A turbine offers some advantages over a piston engine. The number of moving parts is much smaller, and the power to weight ratio is much higher. A turbine of a given power output is also physically smaller than an equally powerful piston engine, allowing a locomotive to be very powerful without being inordinately large. However, a turbine's power output and efficiency both drop dramatically with rotational speed, unlike a piston engine, which has a comparatively flat power curve.

Gas turbine locomotives are very powerful, but also tend to be very loud. Union Pacific Railroad operated the largest fleet of gas turbine-electric locomotives in the world, and was the only railroad to use them for hauling freight in regular service. Most other GTELs have been built for small passenger trains, and only a few have seen any real success in that role.

After the 1973 oil crisis and the subsequent rise in fuel costs, gas turbine locomotives became uneconomical to operate, and many were taken out of service. This type of locomotive is now rare.

Fuel cell-electric

In 2002 the first 3.6 tonne, 17 kW hydrogen (fuel cell)-powered mining locomotive was demonstrated in Val-d'Or, Quebec. In 2007 the educational mini-hydrail in Kaohsiung, Taiwan went into service. The Railpower GG20B finally is another example of a fuel cel-electric locomotive.

Slug or Drone

A slug or drone locomotive is a non-powered unit attached to a diesel-electric locomotive to provide additional traction and braking capability. The slug has traction motors but no engine, power being supplied by the attached locomotive (known as a 'mother'). At slow speeds, a diesel-electric prime mover can potentially produce more power than can be usefully used by its own traction motors; a slug increases the number of traction motors available to use the power more effectively.

Slugs are mainly used in rail yards for switching duties, in which case they are normally built without a cab. Other slugs, designed for use on service trains, may be fitted with a cab, which can control the whole consist, and may also provide additional fuel storage for the mother locomotive. In recent years, conventional locomotives have been used in place of slugs on service trains, remotely controlled from the lead locomotive configuration.

CP Rail used a prototype drone locomotive system called LOCOTROL which evolved into today's systems.

Use

A brass makers plaque from an Andrew Barclay locomotive of 1925.

The three main categories of locomotives are often subdivided in their usage in rail transport operations. There are passenger locomotives, freight locomotives and switcher (or shunting) locomotives. These categories determine the locomotive's combination of physical size, starting tractive effort and maximum permitted speed. Freight locomotives are normally designed to deliver high starting tractive effort—needed to start trains that may weigh as much as 15,000 tons—and deliver sustained high power, at the sacrifice of maximum speed. Passenger locomotives develop less starting tractive effort but are able to operate at the high speeds demanded by passenger schedules. Mixed traffic locomotives (US English: general purpose or road switcher locomotives) are built to provide elements of both requirements. They do not develop as much starting tractive effort as a freight unit but are able to haul heavier trains than a passenger engine.

Most steam locomotives are reciprocating units, in which the pistons are coupled to the drivers (driving wheels) by means of connecting rods. Therefore, the combination of starting tractive effort and maximum speed is greatly influenced by the diameter of the drivers. Steam locomotives intended for freight service generally have relatively small diameter drivers, whereas passenger models have large diameter drivers (as large as 84 inches in some cases).

With diesel-electric and electric locomotives, the gear ratio between the traction motors and axles is what adapts the unit to freight or passenger service, although a passenger unit may include other features, such as head end power (also referred to as hotel power or electric train supply) or a steam generator.

Some locomotives are designed specifically to work mountain railways, and feature extensive additional braking mechanisms and sometimes rack and pinion. Steam locomotives built for steep rack and pinion railways frequently have the boiler tilted relative to the wheels, so that the boiler remains roughly level on steep grades.

Operational role

Sometimes a locomotive will work in a specific role, such as:

- **Train engine** is the technical name for the locomotive which is attached to the front of a railway train for the purpose of hauling that train. Exceptionally, where operating facilities exist for push-pull operation, the train engine may be attached to the rear of the train;
- Pilot engine – a locomotive attached in front of the train engine, to enable Double-heading;
- Banking engine – a locomotive temporarily assisting a train from the rear, due to a difficult start or a sharp incline gradient;
- Light engine – a locomotive which is operating without a train behind it, usually because it needs to be relocated for operational reasons.
- Station pilot – a locomotive used for shunting passenger trains at a railway station.

Wheel arrangement

Wheel arrangement is one type of classification. Common methods include the AAR wheel arrangement, UIC classification, and Whyte notation systems.

Remote control locomotives

In the second half of the twentieth century remote control locomotives started to enter service in switching operations, being remotely controlled by an operator outside of the locomotive cab.

Locomotives in numismatics

Locomotives have been a subject for collectors' coins and medals. One of the most famous and recent ones is the 25 euro 150 Years Semmering Alpine Railway commemorative coin. The obverse shows two locomotives: a historical and a modern one. This represents the technical development in locomotive construction between the years 1854 and 2004. The upper half depicts the “Taurus”, a high performance locomotive. Below is shown the first functional Alpine locomotive, the Engerth; constructed by Wilhelm Freiherr von Engerth.

Locomotives

Steam locomotive B-5112 in Ambarawa Railway Museum, Indonesia

WDM-3A diesel passenger and freight locomotive of Indian Railways at Shantiniketan, India

Spanish modern electric locomotive with talgo cars; AVE Class 102 type train

EMD GP50 diesel-electric freight locomotive of the Burlington Northern Railroad

Swiss Electric Locomotive at Brig, Switzerland, note the Alps at top right corner

Chapter 2

Bilevel Rail Car

Double-deck rail car operated by GO Transit, Ontario, Canada

Bombardier double-deck rail cars in Germany, used extensively on suburban trains (here: S-Bahn Rostock)

The **bilevel car** (North American English) or **double-decker train** (British English) is a type of rail car that has two levels of passenger accommodations, as opposed to one, increasing passenger capacity (in example cases of up to 57% per car).

The use of double-decker carriages, where feasible, can resolve capacity problems on a rail line via rolling stock improvements - rather than via the other options of longer trains (which require longer stations), more trains per hour (which the signalling / safety requirements may not allow) or adding extra tracks besides the existing line (which is very expensive).

Bilevel trains have also been argued as improving the (ecologic) sustainability of rail transport, due to their higher efficiency, and some have even gone so far as to laud them as having saved some American transcontinental lines which would otherwise have been shut down for lack of (financial) efficiency.

However, the great height of the cars can limit their use, especially in countries with low loading gauges. Some countries like the United Kingdom are therefore intentionally constructing future lines (or upgrading existing lines) to higher gauge standards to enable double-decker trains. An other disadvantage that has sometimes been cited are issues that may be created at train stations when much larger numbers of passengers try to board or disembark at the same time.

Typical design

The double-deck design usually includes lowerering the bottom floor to below the top level of the wheels, closer to the rails, and then adding an upper floor above. Such as design will fit under more bridges, tunnels and power wires (structure gauge). For cost and safety, this design also minimizes car height (loading gauge) and lowers the centre of gravity.

Depending on train station platform heights, three designs can be used for entry - high platforms require use of a "split level" car design, where the doors are located on a middle level, with access into the upper or lower level branching off - with stairs or ramps going both up and down (sometimes this configuration includes a section of seating at the middle level in the entry section, with double levels only in part of the lengths of the car). For low train station platforms, a "two floor" design with level entry onto the lower floor is used. Occasionally a third, very tall "two floors over-wheel" design is used. This is a traditional single floor car "with a second story" design with, when using low platform, requires steps up to a traditional floor height and then internal stairs up to the upper floor.

Platform height and floor height issues

There are four important height measurements above the railhead: platform height, traditional floor height, downstairs floor height and upstairs floor height. Platform height determines the level entry height for wheeled objects, such as luggage, strollers, wheelchairs and bicycles. Platform height is ideally standardized across all stations the train serves. Traditional rail car floor height matters for end doors connecting to existing single floor rail cars. Downstairs or lowest floor height is primarily determined by the thickness of the beams connecting the span between the wheels and bogies (trucks) of a rail car. The upstairs floor or highest floor height is above the lowest floor and must fit under bridges and tunnels. Level entry floor height must match the platform height. Hopefully either the traditional or downstairs floor height already matches the platform height. Despite the name "bilevel" or "double-decker", for maximum compatibility the rail car will have up to four different floor heights. Using outside steps to avoid having a level entry from the platform is troublesome.

Common High Platform Design

Most high platform trains have level entry over the bogie with stairs inside the car for the upstairs and downstairs double-decker floors. These cars are designed for high platform rail line, such as all the existing stations with a standardized high platform and the rolling stock end doors that connect to any traditional single floor car and even roof line aerodynamics. There are three floor heights (upstairs, downstairs, and platform levels) in these "split level" cars. The entry level floor area has to be big enough to hold wheel chairs, children push-carts, and even wheeled luggage. This high platform "split level" double-decker design is the preferred design in urban and commuter applications, and can be designed to matched to any rail platform height. Car roof lines lengthwise are sloped at each end (not flat) for aerodynamic connection to single level cars and the space is unused. Bombardier commuter cars are 15 ft 11 in (4,850 mm) high.

Common Low Platform Design

Most low platform double-decker trains have level entry onto the lower level of the car, allowing wheelchair access. There are two floor heights (upstairs and downstairs) in these "bilevel" cars. There is a staircase between floors inside the car. Connecting doors between cars are at the (higher) upper floor height and not at the traditional height. These low platform cars use low platform stations across the Western US, because the traditional single floor trains all had exterior entry steps to maximize flexibility (emergency and temporary stops) and minimize infrastructure costs. There are no examples of two floor platforms, so there are no platform doors on the upper floor. Car roof lines lengthwise are flat for connecting doors to the upstairs of bi-level cars. Connecting directly to a single level car causes drag and connecting door problems. A Bombardier Amtrak Superliner car is 16 feet 2 inches (4,930 mm) tall.

Uncommon Very Tall Design

There are several very tall bilevel cars (e.g. Colorado Rail has 19 feet 9.5 inches (6.033 m) or 6033 mm). They typically are described as a traditional rail car with a second story. Most of these cars serve low platforms so they have exterior steps up to the traditional "over-wheel" floor height (e.g. US 51 in (1,300 mm). End doors connect at the traditional height of existing rolling stock. Some cars have upstairs end doors as well. Upstairs and downstairs connect by interior stairs. These cars can fit the most able people, but lack level entry. Some cars are self-propelled Multiple Units so using traditional floor heights appears fixed. In towed cars it is possible to lower the downstairs floor between the wheels/bogies so that level entry is possible with more than 500 mm of added headroom and interior steps from that floor to the traditional floor.

Alternatives

The alternatives to double-decker cars are usually explored first, before going double-decker.

- **Add cars to existing trains**: this works until platform and siding capacity has been used. Until that occurs, lengthening trains is preferable to changing the loading gauge and structure gauge of the rail line. Longer cars (without changing structure gauge) does not add much, because cars are often required to be narrower to negotiate curves. In countries with larger structure gauges for freight traffic (such as the United States) this is often less of a concern.

- **More trains**: increase the frequency of trains scheduled. This added flexibility compared to the same capacity via bilevel cars is generally very popular with passengers. However, it may cause congestion on the rail line, eventually preventing more capacity from being added in this way.

- **Changing seating**: fitting more (smaller) seats into the same space and/or decreasing the pitch (distance between seats) or removing seats completely on existing vehicles.

- **Track amplification**: building additional rail lines and platforms is expensive and often requires land acquisition and service disruptions.

If freight service has increased the structure gauge, and the rail line needs to minimize "per car" maintenance and staffing costs, double-deckers can pay for themselves more quickly than buying single-floor cars of equal capacity. Wheelchair accessibility laws encourage level entry solutions frequently provided by double-decker rail cars. Profitability is encouraging double-decker rail car adaptation before many alternatives.

Operators

Interior of a Cityrail Tangara carriage in Sydney

Australia

In 1964, Tulloch Limited built the first double-decker trailer cars for use in Sydney. They ran with single deck electric motor cars. The first prototype double deck motor car was built by Comeng in 1969 and production versions entered service in 1972. These were the first fully double deck Electric Multiple Unit passenger trains in the world. All CityRail electric commuter trains in Sydney are now double deck. They all have two doors per side per carriage, with a vestibule at each end at platform height. Well-known examples of these trains are the Tangara and Millennium trains. The Sydney double deck commuter trains are 14 ft 4.5 in (4,382 mm) high.

The Public Transport Corporation in Melbourne ordered a prototype Double Deck Development and Demonstration train in 1991. It suffered frequent breakdowns and spent long periods out of use. It was finally withdrawn in 2002 and scrapped in 2006.

Canada

Several regional commuter rail operators used bi-level cars in their fleet. GO Transit's passenger fleet are all Bombardier Transportation Bi-level cars. Others include:

- West Coast Express
- Agence métropolitaine de transport

Tour operator Rocky Mountaineer also uses bi-level cars.

Ontario Northland's Polar Bear Express operates a domed car that has two levels, but it is not technically a bi-level car.

AMT also operated Canadian Vickers bi-level cars and currently ordering Bombardier Transportation Multi-level cars.

Finland

Double-decker Inter City train in Finland

In Finland, VR began operating double-decker sleeping cars on 1 February 2006. The two-bed cabins on the upper deck have toilets and showers while cabins on the lower deck use shared ones. VR also operates double-decker InterCity trains with at seat power supplies for laptops.

France

French suburban double-deck train.

The Chemin de Fer de l'État in France ran voitures à 2 étages double-deck suburban coaches from 1933. Its successor, the SNCF, has been running VB2N double-decker coaches since 1975; VB2N were introduced from 1975 as a replacement of the État cars.

Since the late 1980s, SNCF has been running double-deck RER trains. SNCF runs double-deck TGV cars on heavily used high-speed services. Many suburban, regional and high-speed services are operated by double-deck DMUs, EMU, coaches and TGV. The French loading gauge dictates that the double-deck cars have a maximum height of 4200 mm or 13'-9.35".

Hong Kong

MTR and formerly KCRC operates double-decker carriages with the KTT train sets. These cars were manufactured in Japan by Kinki Sharyo T1 (T1C), T2 (T2A, T2B).

Japan

Kintetsu 30000 series Vista Car introduced in 1978

In Japan, double-decker trains are used either to show better scenery, or to increase seat capacity.

For scenery viewing

The first Japanese double-decker train appeared in 1904. It was Type 5 train of Osaka City Tram, once operated by Osaka Municipal Transportation Bureau. The tram car, however, soon took away its second floor, due to the complaints by residents along the line, concerning their privacies.

The first double-decker heavy rail train, the Kintetsu 10000 series, appeared in 1958. The series, nicknamed "Vista Car", became popular trains used for limited express services. Its successors are still used by Kintetsu. The idea of Vista Car is said to come from Vista Dome Car in United States. The first double-decker high-speed rail in the world was JNR 100 Series Shinkansen used from 1986. The train was purely introduced to improve its luxury. The upper floor of the train was used for Green car accommodation and a dining car.

Other double-decker sightseeing trains include the JR Shikoku 5000 series, JR Hokkaidō KiHa 183 series, Keihan 8000 series, JR Central 371 series, and Odakyū 20000 series RSE.

A similar kind of trains are largely single-decker trains with vehicle cockpit domes on the "second floor", to allow the better front view. This kind of trains include Panorama Cars by Meitetsu, Romancecars by Odakyū, and *Mount Fuji Limited Express* by Fujikyū.

For increased capacity

E4 series Shinkansen

The first Japanese double-decker trains built to increase its capacity were 211 series and 113 series, both by JR East, 1989. These trains were *Green Cars* (Japanese for first class cars), needing more seats than standing spaces. JR East also introduced an experimental 415 series double-decker car with normal class seats on the Jōban Line in 1991, and the 215 series EMUs for *Home Liner* services in 1992. JR East continues to use double-deckers, including E217 series for Sōbu Line (Rapid) and Yokosuka Line, E231 series for Tōkaidō Main Line, Utsunomiya Line (Tōhoku Main Line), Takasaki Line, and Shōnan-Shinjuku Line, and E531 series for the Jōban Line.

In Japan, however, double-decker commuter trains are relatively fewer than those used in Europe or North America. This is because Japanese commuter trains can be much more crowded than Western counterparts. Therefore, they generally need more standing spaces than seats. Also, Japanese train cars are 20 m long or less, and it is technologically difficult or inefficient to have more than 2 doors on each side of double-deckers that size. Japanese crowded trains, however, generally need 4, 5, or 6 doors on each side to make smooth boarding and alighting.

JR East also introduced E1 Series and E4 Series for its Shinkansen Lines. Unlike 100 Series in the past, these trains, nicknamed "Max", all consist of double-decker cars, and are purely made to increase their capacities. In that sense, these trains are similar to TGV Duplex in France. There are also some double-decker sleeping cars made to increase their beds or compartments, like CityNightLine trains in Europe. This includes JR West 285 series EMUs for *Sunrise Izumo/Sunrise Seto* and JR East E26 series cars for *Cassiopeia* services.

Sweden

X40 arriving in Eskilstuna.

SJ AB operates 43 double-decker EMUs built by Alstom and designated class X40. The EMU comes in a two-coach version and a three-coach version. The trains are mainly used in regional trains in the areas around lake Mälaren and in the trains between Gävle and Linköping. It has a maximum speed of 200 km/h (125 mph) and are equipped with wireless internet.

Between 1966 and 1990 SJ used DMUs of class Y3 with double-decker end cars and normal cars in between. Due to the to distinct humps on the endcars it was nicknamed "the camel".

Switzerland

IC 2000 between Zürich and Luzern with the control car leading the train

Double-decker commuter trains are used by the Zürich S-Bahn. Two types of trains are used, an older type consisting of an electric locomotive with double-decker cars, and Electric Multiple Units (DMU or EMU) where the motors are on board the car. From 2010 onwards, a third type – the Stadler DOSTO – is scheduled to enter service.

The Swiss Federal Railways also operate the IC 2000 double-decker passenger coaches in most of Switzerland.

United Kingdom

In the United Kingdom, and countries with a similarly small loading gauge, the railway system cannot accommodate double-deck trains. A modest attempt at double decking was made in 1948 on the Southern Railway with the two trains of the Bulleid 4DD class. Although innovative, with stepped compartments, where the bottoms of the upper seats are above the heads of the people on the lower level, but the feet of the people above are not, see, the loading gauge severely restricted their use and they were removed from service in 1971. However, the Channel Tunnel Rail Link (High Speed 1) was built to European loading gauge standards and is therefore capable of taking double-decker trains. However, nobody has yet expressed an interest in running double-decker trains along this line.

Double-decker trams were common in British cities prior to the dismantling of the networks between the 1930s and 1960s.

USA

Multi-level New Jersey Transit train with quarter-point and end doors.

Passenger cars are manufactured by Bombardier, Kawasaki, Colorado Railcar, IC2000, and several others, with the former two having produced the majority of the High platform "split level" commuter rail cars in use in the Northeast US.

Colorado Railcar make DMUs and IC2000, of Switzerland, make EMUs, where the Multiple Units are self-propelled cars, much like subway cars. Colorado Railcar cars are very tall (19 ft 9.5 in or 6,033 mm) cars for low platforms with steps entry to a normal (51 in or 1,300 mm) floor and an upstairs. The IC2000 cars are strictly low platform design.

Other designs, including rolling stock made by Colorado Railcar Manufacturing, Budd, Pullman-Standard, Bombardier and others, have the entrance on the lower deck rather than an intermediate level. Amtrak Superliners are double-decker cars of this variety, with the entrance a step or so up from the lowest station platform level, or at the level of slightly higher platforms, and allow passage from car to car at upper-deck level.

The northeastern US can accommodate split level (double deck) cars only if they are no higher than 14.5 ft (4,420 mm) due to loading gauge restrictions (i.e. bridges, tunnels, etc. are too low). Bi-level cars that run on the Long Island Rail Road and on New Jersey

Transit were built by Bombardier Transportation to clear these height restrictions. The designs found on these two railroads are based on a 1930s Pullman Sleeping Car design for the Pennsylvania Railroad called a Duplex Sleeper. This design provided 24 Roomettes on two levels with the lower level depressed between the trucks. This idea was copied in 1947 for the Long Island Rail Road, making use of a standard P-70 that was electrified. Current bi-level cars have the entire center sill lowered to the minimum level between the trucks, providing a depressed floor on that level. The upper level is stacked on top between the trucks. At each end, the a common floor is located at normal height over the trucks. While Long Island Rail Road's cars have only two quarter-point doors on each side for high level platforms, New Jersey Transit's cars have four doors on each side, two quarter-point doors at high level platform height and two in the normal Vestibular position, with stairs to reach low level platforms. Similarly the structure gauge of the Mount Royal Tunnel limits the height to 14'-6" or 4420 mm. The Massachusetts Bay Commuter Rail is the only operator on the Northeast Corridor who operates bi-level cars that exceed the 14.5 ft (4,420 mm) loading gauge restriction. The bi-level cars in use by the MBCR were produced by Kawasaki Rail Car, Inc. and have a similar configuration to those used by the LIRR and NJ Transit, but differ in that they only have vestibular side-loading doors.

The double deck cars operated by Chicago's Metra regional rail service are known as "gallery cars" as there is an open space between the two sides of the upper deck, allowing ticket collectors to check tickets on both levels from the bottom level. Chicago does not have the loading gauge problems that affect most eastern US cities (although ex-Metra cars operate on MARC in Baltimore, Maryland), so all Chicago's commuter rail rolling stock is full size bi-level, and many of Amtrak's Superliner trains to the western USA originate from Chicago.

The first bi-level gallery cars were introduced by the Chicago, Burlington & Quincy railroad in 1950.

Other countries

Dutch bilevel train at station Amsterdam Bijlmer ArenA

In the Netherlands, there are two types of double-deck trains, the DDM and the DD-IRM, also called Regiorunner. The DD-IRM, is an example from the Netherlands, of High platform (split level) double-decker cars. It is one step up from the station platform to the entrance, and from there seven steps upstairs or four steps downstairs.

In Spain several lines of Cercanías (Renfe's commuter rail service) use double-deck trains. Bombardier's double-deck rail cars in Germany are also used extensively on suburban trains by the DB. The same rail cars serve some of the routes on the Israel Railways network, hauled by diesel locomotives and include electric generators housed in the control car.

In Iran, the Tehran-Hashtgerd suburban commuter line is served with electric push-pull hauled trainsets with double-decker carriages manufactured by Wagon Pars in Iran.

In Hong Kong, the Kowloon-Canton Railway Corporation uses double-deck cars, named "Ktt", on its cross-boundary route between Kowloon and Guangzhou. In January to May 1998 the "Ktt" cars were used to serve between the Hung Hom and Lo Wu stations. The "Ktt" cars have lower bottom floor than the ordinary single-deck cars serving on the same pair of tracks.

In China, Changchun Railway Vehicles offers a double deck coach, Type SYZ25B, that is similar to Superliner (railcar).

In India, the Flying Ranee, a passenger Train between Surat and Mumbai Central on the Western Railway Track uses double-deck cars.

Russian Railways plan to start using double-deckers in 2011 manufactured by Transmashholding in cooperation with Alstom.

Gallery cars

A Nippon Sharyo bi-level passenger car operated by Caltrain

Because of the two levels being separate on most cars, there is a physical limitation on the conductor, as it is difficult for him to verify, collect payment and sell tickets to such a large concentration of passengers in one car on each level, owing to the sometimes short distance between stops.

A solution came in the form of the design of the "gallery" car, which features upper levels, which are "mezzanines" or "balconies" running along both sides of the car, with an open area between them. Some gallery cars have up to four separate galleries (one on each side, times two for access from each end).

This enables the conductor(s) walking along on the lower level to easily reach up and punch or validate tickets of the passengers seated on the mezzanine level. Passengers can place their tickets in clips along a lengthwise panel, located slightly above the conductor's head and within easy reach. The conductor can then quickly check tickets and move to the next car.

Another advantage of bilevel gallery cars is the relatively low first step of the vestibule entrance to the car, which is $14\frac{5}{8}$ inches (371 mm) above the head of the rail. The advantage of this is that commuter rail operators do not have to spend funds on building high-level platforms; a low-level platform is all that is necessary, at a far lower cost. This can be a major disadvantage as well, as many commuter rail systems prefer high-level platforms as they can decrease loading and unloading times substantially, and greatly improve access to trains for the disabled.

Such cars are used by Metra in and around Chicago, Caltrain, and Montreal's Agence métropolitaine de transport. They provide high capacity (155 to 169 passengers each). Chicago's commuter rail system is currently receiving new versions of these cars and Caltrain, the San Francisco peninsula commuter rail service, has recently overhauled its fleet. Virginia Railway Express (VRE) and MARC Train in Maryland are also owners of gallery cars in the Washington DC Area. Many of the gallery cars these commuter railroads use are ex-Metra cars.

Downsides of gallery cars are the often narrow and difficult access to the seats.

In container transport

Similar to passenger cars, one may also have bilevel cargo cars. In intermodal freight transport, many modern types of container well cars cars are designed to accommodate "double-stacking." Where passengers and freight rail use the same lines, containers may have required increasing the lines' structure gauge. Passengers and freight are usually separated. Containers are 8 feet (2.4 m) wide and 8.5 feet (2.6 m) tall or sometimes 9.5 feet (2.9 m) tall. Therefore double stack freight is 17, 18 or 19 feet (5.8 m) above well car floor height.

Chapter 3

Control Car (Rail)

Modern German InterCity *Steuerwagen* cab car.

A **control car** is a generic term for a non-powered railroad vehicle that can control operation of a train from the end opposite to the position of the locomotive. They can be used with diesel or electric motive power, allowing push-pull operation without the use of an additional locomotive.

Cab cars are control cars similar to regular passenger car, but with a full driver's compartment built into one or both ends. They can be very similar to regular railcars, to the point of including a gangway between cars so that they could be used in the middle of a passenger train like a regular car if necessary. They appeared for the first time in the United States and France in the 1960s.

Trains operating with a locomotive at one end and a control car at the other do not require the locomotive to run around to the opposite end of the train when reversing direction at a terminus. Control cars can carry passengers, baggage, mail or a combination thereof, and may contain an engine-generator set to provide head end power.

In addition to the driver's cab, which has all the controls and gauges necessary for remotely operating the locomotive, control cars usually have a horn, whistle, bell, or plough (as appropriate), and all of the lights that would normally be on a locomotive.

Control method

In Britain, a common method is to control the train through a Time-Division Multiplexed (TDM) connection. In North America and Ireland a standard AAR 27-wire multiple unit cable with jumpers between cars is the preferred method.

North America

Some commuter rail agencies in the United States routinely use cab cars in place of regular passenger coaches on trains. The Chicago and North Western Railway had 42 control cabs built by Pullman-Standard in 1960, which eliminated the need for its trains or locomotives to be turned around. It was an outgrowth of multiple-unit operation that was already common on diesel locomotives of the time.

During the mid-1990s, as push-pull operations became more common in the United States, cab-cars came under criticism for providing less protection to engine crews during grade crossing accidents. This has been addressed by providing additional reinforcing in cab cars. This criticism became stronger after the 2005 Glendale train crash, in which a Metrolink train collided with a Jeep Cherokee at a level crossing. The train was traveling with its cab car in the front, and the train jacknifed.

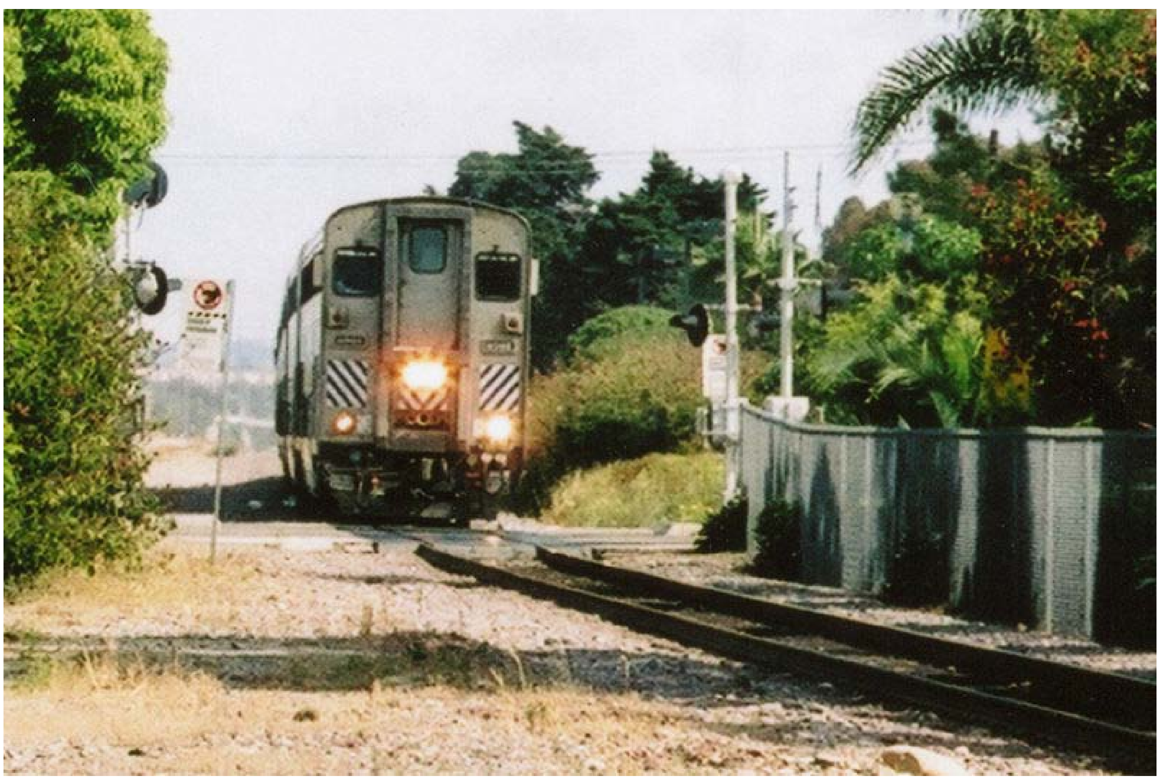
Amtrak non-powered control unit (NPCU) No. 90218 in Galesburg, Michigan.

Converted locomotives

From the 1970s until 1999, the Long Island Rail Road used a number of older locomotives converted to "power packs". The original prime movers were replaced with 600 horsepower (450 kW) engines/generators solely for supplying Head End Power or HEP with the engineer's controls left intact. Locomotives converted included Alco FA-1s, FA-2s, EMD F7s and one F9. Ontario's GO Transit had a similar program for EMD FP7s.

Amtrak developed their Non-powered Control Units (NPCUs) by removing the prime mover, main alternator, and traction motors from surplus F40 locomotives. The control cab was left in place, as were equipment allowing horn, bell & headlight operation. A floor and roll-up side-doors were then installed to allow for baggage service leading to the nickname "cab-baggage cars" or "cabbages."

Northstar Line cab car (BiLevel Coach) in Elk River, Minnesota



Pacific Surfliner cab car in Carlsbad, California

NJ Transit Comet V Cab Car in Bay Head, New Jersey

Europe

In Britain, this type of car is called a *driving trailer* and mostly this term is also used on the Continent. There are many examples of this type of vehicle in operation in Europe.

Austria

Austrian NPZ EMU Steuerwagen of the Montafonerbahn in Schruns

The Steuerwagen of the Austrian CityShuttle in Lower Austria

Belgium

SNCB make extensive use of push-pull working. Trains are powered by class 27 or class 13 electric locomotives and are operated in one direction from a driving carriage.

Germany

The German term for control cars is *Steuerwagen*.

The first German attempts to use control cars and remote control-equipped steam locomotives were before the Second World War by the Deutsche Reichsbahn (DRG). The driver's control instructions were transmitted from the control car to the locomotive by a Chadburn-type machine telegraph (similar to engine order telegraphs on ships). The order had to be immediately acknowledged and implemented by the automatic firebox controllers. This indirect control was judged as impractical and unsafe because, although the driver controlled the brake directly, the danger existed that in an emergency the locomotive would continue supplying "push" power for some time and possibly derail the train.

Attempts to use electric locomotives (beginning with a converted E 04 class model) were more promising, as the engine driver could control the locomotive directly. World War II interrupted the test program, despite good successes. Only after the war would control car operation be slowly accepted, when locomotives and suitably equipped cars became available.

The length of train consists in push-pull operations was originally limited to 10 cars for reasons of guidance dynamics. A speed limit of 120 km/h was also imposed, rising to 140 km/h in 1980. This was not an operational hindrance, as push-pull trains were generally initially used in six-car commuter trains.

Only since the mid 1990s have long-distance trains, which can have up to 14 cars and travel at speeds of 200 km/h, been operated with control cars. A special circumstance is the ICE 2, which may operate with the control car in the lead at up to 250 km/h on the recently built high-speed lines.

ICE2 Steuerwagen at Cologne-Bonn Airport

Different livery on a double-decker German Steuerwagen

German InterRegio livery in Heidelberg

Modern German version in an older livery

Frontal view of the German model

A German commuter train clearly showing the locomotive driving from the rear

Ireland

Iarnród Eireann operates three classes of push-pull trainsets, each with its own Control Car:

- Mk 3 with driving cab containing replica locomotive control stand, luggage compartment, under-slung Cummins engine / generator set for train heating and passenger seating.
  - Numbered 6101 - 6105, converted from Mk 3 intercity cars for suburban push-pull service.
- De Dietrich (Enterprise service) with driving cab containing EMD control stand, luggage compartment and passenger seating. On this set, train heating is supplied from the locomotive Head End Power System.
  - Numbered 9001 - 9004
- CAF (Mk IV) with driving cab containing replica locomotive control stand, luggage compartment and twin engine / generator sets for train heating. No passenger seating is provided.
  - Numbered 4001 - 4008

All the Control Cars have full-sized driving cabs with EMD locomotive type power and brake controls. Locomotive control is by means of an AAR system, modified by Iarnród Éireann (IE) to include control of train doors and operate with IE 201 Class locomotives.

An Enterprise DVT at Dublin Connolly

CAF Control Car (GC), 2006

Italy

In Italy the first push-pull trains began to run after World War II.

At the time there were no systems to actually remote command the rear locomotive, so an engineer had to take place in it and command traction, following instructions (via an apposite intercom) given by the other driver, who remained in the front car, commanding brakes and sighting signals. This lasted until the adoption of the 78-wire cable in the 1970s, which enabled full remote commanding from control cars.

Today push-pull trains are very common, and different kinds of control cars are employed:

- **UIC Z1** control cars.
- **MDVC** type control cars, with aerodynamic or communicating cabin.
- **Piano ribassato** type control cars, with flat, refurbished E464-like or communicating cabin.
- **Doppio Piano** two floors control cars.
- **UIC-X** type control cars.
- **Vivalto** type control car.

These types allow full remote control of any Italian locomotive supplied with standard 78-wire cable, except for UIC Z1, which are used on IC services and are only able to command class E.402 locomotives, and MDVC diesel specific version, usable only with class D.445 diesel locomotives.
The same driving commands are used for both rheostatic and electronic locomotives, but their meanings change.

Vivalto type control cars, at this time, can only remote command Class E.464 and Class E.632 locomotives, because of software issues, tough are able to command other locomotive types. Vivalto cars can also use TCN remote control cable.

Driving cars can be recognized because of the "**np**" in their identification number and usually also have a dedicated compartment for bicycle and luggage transportation.

There also are specific EMU/DMU non-motorized units control cars, which (in Trenitalia) are classified as Le / Ln XXX; no significant difference between them and motorized units, except the lack of traction motors.

Trenitalia refurbished Piano Ribassato driving carriage with E.464-like cabin.

Two floors driving carriage in Udine station in 1997.

Trenitalia UIC-Z1

The Netherlands

NS use their driving carriages in two different strategies.

For short distance trains they use a "virtual EMU" concept. Train sets are formed of a driving carriage, two or three intermediate carriages and either a class 1700 electric locomotive or an EMU motor vehicle. These train sets are diagrammed as if they were all EMUs resulting in formations with two locomotives, often at intermediate positions in the train.

For longer distance workings, including the Benelux services to Brussels the more normal mode of operation is used.

Switzerland

Swiss driving trailers operate in many different configurations. There are several models currently in service on S-Bahn networks as well as regional, InterRegio, and InterCity services. These are operated by the federal railway system (SBB) as well as various private railroads throughout the country (including narrow gauge lines) and into France, Germany, and Italy.

Driving trailers are classified after the UIC-lettering system, adding a "t," giving *Bt* (second class), *BDt* (second class + baggage), *ABt* (first + second class), or *Dt* (baggage).

For Intercity trains there are the Bt IC that work together with EW IV and the double-deck version for the IC 2000 trainsets, working with Re 460.

The Zürich S-Bahn trainsets with Re 450 work in fix consists of Re 450 - B - AB - Bt but intermediate cars and driving trailers are numbered as coaching stock.

"NPZ" Regional and S-Bahn trains with RBDe 560 usually have a matching Bt driving trailer. Replacement by an older BDt EW I/II is technically possible. Older driving trailers, mostly BDt EW I/II and a few remaining Dt of SBB can be used with Re 420 and RBe 540 and some motive power of private railways. In theory also Re 430 and Re 620 can be controlled but these classes only work freight trains today.

The BLS operates four groups of driving trailers:

- ABt NPZ to go with RBDe 565 and RBDe 566 II (ex RM)
- ABt of a modified type EW I for RBDe 566 I (ex RM)
- Bt EW III, BDt EW II (both ex SBB), Bt EW I 901-902 (ex Thurbo/MThB) and leased Dt from SBB can work with Re 420.5 ex SBB and BLS Re 465.
- Bt EW I 950-953, BDt 940-941, car-shuttle BDt 942-945, 946-949 and 939 can work with Re 425, Ae 4/4 and Re 465

Südostbahn had a fleet of ABt for their BDe 4/4 but they will soon be fully replaced by FLIRTs. NPZ ABt exist for the two types of RBDe 566 SOB ownes (566 071-076 ex BT and 566 077-080 ex SOB of the SBB-type). Nine BDt are used for the Voralpen-Express with Re 456, Re 446 or SBB-CFF-FFS Re 420.

The narrow gauge Zentralbahn ABt can control HGe 101 (ex SBB), De 110, BDeh 140 (ex LSE) and the new "SPATZ" ABe 130.

The Rhaetian Railway (RhB) has, besides the ABDt that work with Be 4/4 511-516, a group of driving trailers that can be used with their Ge 4/4 I, II and III locomotives. Three of them are specially fitted for Vereina car shuttle trains.

The Matterhorn-Gotthard-Bahn (MGB) has numerous driving trailers for almost all types of motive power. They work regional trains and car shuttle trains through the Furka Base Tunnel.

The Swiss Bt IC model in Zürich

Double-decker Swiss IC 2000 Steuerwagen

S-Bahn Zürich double decker

Swiss NPZ Steuerwagen in Biel

SBB BDt Steuerwagen near Wil

Swiss MThB Bt EW I Steuerwagen in Konstanz

The BLS Bt EW III (former Swiss Express)

An ABt Steuerwagen ex Furka-Oberalp for Deh 51-55 and 91-96 in Andermatt

Bt ex BVZ for Deh 4/4 21-24 at Stalden in the Valais

United Kingdom

Control cars have been in use in the United Kingdom for many decades, with the Great Western Railway often using 'autocoaches' on branch line services. These allowed a train driver to remotely control the regulator and reverser of a suitably equipped locomotive. The fireman remained on the locomotive to operate the boiler and locomotive whistle. Locomotives were commonly sandwiched between a pair of autocoaches, allowing a maximum of four to be used.

- **Driving Brake Standard Open**

A Driving Brake Standard Open or **DBSO** is a specially converted passenger car. These have not been used on mainline passenger trains since 2006, but some have been refurbished for use on Network Rail test trains.

DBSO 9710 at Norwich

DBSO in different livery

- **Driving Van Trailer**

A Driving Van Trailer or **DVT** is a more modern type of control car, purpose-built to include space for baggage and a guard's office. The DVT was developed from the DBSO and originally designed to be used with British Rail Mark 3 and Mk 4 coaches. DVTs are in service with East Coast (Mk 4), Virgin Trains (Mk 3), National Express East Anglia (Mk 3) and Wrexham & Shropshire (Mk 3).

New Zealand

In Auckland, Veolia (New Zealand) operates 14 DC class locomotives (owned by KiwiRail) in push-pull mode with 12 sets (2 more on order) of 2-4 (generally 3) SA cars and an SD driving car with driving cab and remote controls (ex British Rail Mark 2 carriages rebuilt for suburban service), owned by ARTA.

Chapter 4

Railroad Car

American Wooden passenger car

British Mark 3 rail coach; an all-steel car from the 1970s

Inside a modern day car from Finland

A **railroad car** (US) or **railway vehicle** (UK and international), also known as a **bogie** in Indian English, is a vehicle on a rail transport system (railroad or railway) that is used for the carrying of cargo or passengers. Cars can be coupled together into a train and hauled by one or more locomotives. Passenger cars can be self-propelled in which case they can be single railcars or multiple units.

Most cars carry a "revenue" load, although "non-revenue" cars exist for the railroad's own use, such as for maintenance-of-way purposes. Such uses can generally be divided into the carriage of passengers and of freight. "Revenue" cars are basically of two types: **passenger cars**, or **coaches**, and **freight cars** or **wagons/trucks**.

Passenger cars

Passenger cars, or coaches, vary in their internal fittings:

In standard gauge cars, seating is usually between three and five seats across the width of the car, with an aisle in between (resulting in 2+1, 2+2 or 3+2 seats) or at the side. Tables may be present between seats facing one another. Alternatively, seats facing the same direction may have access to a fold-down ledge on the back of the seat in front.

- If the aisle is located between seats, seat rows may face the same direction, or be grouped, with twin rows facing each other. Sometimes, for example on a commuter train, seats may face the aisle.
- If the aisle is at the side, the car is usually divided in small compartments. These usually contain 6 seats, although sometimes in second class they contain 8, and sometimes in first class they contain 4.
- In vehicles intended for commuter services seats are sometimes placed with their backs to the carriage side. This gives a wide accessway and standing room which accommodates standing passengers at peak times and improves loading and unloading speeds.

Passenger cars can take the electricity supply for heating and lighting equipment from two main sources - either directly from a head end power generator on the locomotive via bus cables; or by an axle powered generator which continuously charges batteries whenever the train is in motion.

Modern cars usually have either air-conditioning or windows that can be opened (sometimes, for safety, not so far that one can hang out), or sometimes both. Various types of onboard train toilet facilities may also be provided.

Other types of passenger car exist, especially for long journeys, such as the dining car, parlor car, disco car, and in rare cases theater and movie theater car. In some cases another type of car is temporarily converted to one of these for an event.

Observation cars were built for the rear of many famous trains to allow the passengers to view the scenery. These proved popular, leading to the development of dome cars multiple units of which could be placed mid-train, and featured a glass-enclosed upper level extending above the normal roof to provide passengers with a better view.

Sleeping cars outfitted with (generally) small bedrooms allow passengers to sleep through their night-time trips, while couchette cars provide more basic sleeping accommodation. Long-distance trains often require baggage cars for the passengers' luggage. In European practice it used to be common for day coaches to be formed of compartments seating 6 or 8 passengers, with access from a side corridor. In the UK, Corridor coaches fell into disfavor in the 1960s and 1970s partially because open coaches are considered more secure by women traveling alone.

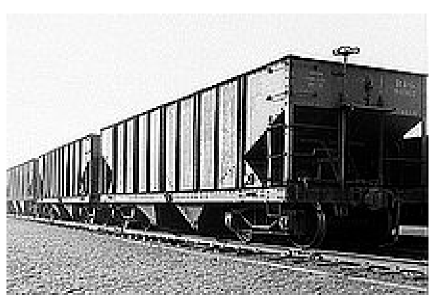
Another distinction is between single- and double deck train cars. An example of a double decker is the Amtrak superliner.

A "trainset" (or "set") is a semi-permanently arranged formation of cars, rather than one created 'ad hoc' out of whatever cars are available. These are only broken up and reshuffled 'on shed' (in the maintenance depot). Trains are then built of one or more of these 'sets' coupled together as needed for the capacity of that train.

Often, but not always, passenger cars in a train are linked together with enclosed, flexible gangway connections that can be walked through by passengers and crew members. Some designs incorporate semi-permanent connections between cars and may have a full-width connection, making in essence one longer, flexible 'car'. In North America, passenger equipment also employ tightlock couplings to keep a train reasonably intact in the event of a derailment or other accident.

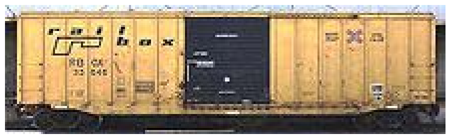
Many multiple unit trains consist of cars which are semi-permanently coupled into sets; these sets may be joined together to form larger trains, but generally passengers can only move around between cars within a set. This "closed" nature allows the separate sets to be easily split to go separate ways. Some multiple-unit trainsets are designed so that corridor connections can be easily opened between coupled sets; this generally requires driving cabs either set off to the side or (as in the Dutch *Koploper*) above the passenger compartment. These cabs or driving trailers are also useful for quickly reversing the train.

Freight cars



American style Hopper Car.

Tank Car.



U.S. type Boxcar.

Articulated Well Cars with containers

A Spine car with a 20 ft tanktainer and an open-top 20 ft container with canvas cover

Freight cars (UK: "wagons" or "trucks") exist in a wide variety of types, adapted to the ideal carriage of a whole host of different things. Originally there were very few types of cars; the boxcar (UK: "van"), a closed box with side doors, was among the first.

- Aircraft Parts Car
- Autorack - (also called *auto carriers*) are specialized multi-level cars designed for transportation of unladen automobiles.
- Boxcar (US), covered wagon (UIC) or van (UIC) - box shape with roof and side or end doors.

- CargoSprinter - a self propelled container flatcar.
- Centerbeam cars
- Coil car - a specialized type of rolling stock designed for the transport of coils of sheet metal, particularly steel. They are considered a subtype of the gondola car, though they bear little resemblance to a typical gondola.
- Conflat (UK) - A flat truck for carrying containers.
- Covered wagon (UIC), van (UIC) or boxcar (US) - fully enclosed wagon for moisture-susceptible goods.
- Covered hopper - similar to open top hoppers but with a cover for weather and temperature-sensitive loads.
- Double-Stack Car (or *well car*) - specialized cars designed for carrying shipping containers. These have a "well" with a very low bottom floor to allow double stacking.
- Flatcar (or *flat*) - for larger loads that don't load easily into a boxcar. Specialized types such as the depressed-center flatcar (aka "well car") exist for oversize items or the Schnabel car for even larger and heavier loads. With the advent of containerized freight, special types of flatcars were built to carry standard shipping containers and semi-trailers.
- Gondola (US) - railroad car with an open top but enclosed sides and ends, for bulk commodities and other goods that might slide off.
- Hicube boxcars
- Hoppers - similar to gondolas but with bottom dump doors for easy unloading of things like coal, ore, grain, cement, ballast and the like. Short hoppers for carrying iron ore are called ore jennys in the US.
- Lorry - An open wagon (UIC) or gondola (US) with a tipping trough, often found in mines.
- Lowmac (UK) - A low-floor wagon for carrying machinery.
- Modalohr Road Trailer Carriers.
- Open wagon (UIC) - railway wagon with an open top but enclosed sides and ends, for bulk commodities and other goods that might slide off.
- Refrigerator car (or *reefer*) - a refrigerated subtype of boxcar.
- Roll-block - a train designed to carry another railway train.
- Rolling highway - a train designed to carry trucks and/or semi-trailers
- Side Dump Cars - used to transport roadbed materials such as, ballast, riprap, and large stone, and are able to unload anywhere along the track.
- Schnabel car - specialized freight car for heavy or oversized loads.
- Slate wagon - specialized freight cars used to transport slate.
- Spine car, a center sill and side sill only car with lateral arms to support intermodal containers. No deck.
- Stock Car - for the transport of livestock.
- Tank car (US), tank wagon (UIC) (or *tanker*) - for the transportation of liquids or gases.
- Tippler (UK), Gondola (US) (or Lorry) - An open wagon with no doors or roof which are unloaded by being inverted on a Wagon Tippler (UK) or Rotary car dumper (US). They are, used for minerals, such as coal, limestone and iron ore as well as other bulk cargo.

- Transporter wagon - a wagon designed to carry other railway equipment.
- "Whale Belly" car, a tank car with a "belly".

The vast majority of freight cars fit into the above categories.

Non-revenue cars

Typical American extended vision caboose.

- Cabooses (or *guard's vans* or *brakevans*) which attach to the rear of freight trains to order to watch the train and assist in shoving moves.
- Clearance car, special car to check for obstructions.
- Handcars, which are powered by their passengers.
- Maintenance of way (MOW) cars, for the maintenance of track and equipment.
  - Tower cars used to maintain overhead lines
  - Track tester
- Rail car mover — some of which resemble HiRail trucks.
- Railroad cranes
- Road-rail vehicle
- Scale test car
- Office car which contains a mobile office for a train company.
- Crew car aka Outfit Car or a Camp Car, a bunk car or modular home mounted on a flatcar to house railroad employees.

Military cars

Armored train Hurban located in Zvolen, Slovakia

Soviet RT-23 Molodets ICBM launch train, in the St Petersburg museum

Military armoured trains use several types of specialized cars:

- artillery — fielding mixture of guns and machine guns
- infantry — fielding machine guns, designed to carry infantry units
- machine gun — dedicated to machine guns
- anti-air — equipped with anti-air guns
- command — similar to infantry wagons, but designed to be a train command center
- anti-tank — equipped with anti-tank guns, usually in a tank gun turret

- platform — unarmoured, with purposes ranging from transport of ammunition or vehicles, through track repair or derailing protection to railroad ploughs for railroad destruction.
- troop sleepers
- DODX is the reporting mark for the United States Department of Defense Military Traffic Management Command. (Index of dodx.)

Mobile missile systems

During the Cold War, the Soviet Union fielded a number of trains that served as mobile missile silos. These trains carried the missile and everything necessary to launch, and were kept moving around the railway network to make them difficult to find and destroy in a first-strike attack. A similar rail-borne system was proposed in the United States of America for the LGM-30 Minuteman in the 1960s, and the LGM-118 Peacekeeper in the 1980s, but neither were deployed. The Strategic Air Command's 1st Combat Evaluation RBS "Express" did deploy from Barksdale Air Force Base with radar bomb scoring units mounted on military railroad cars with supporting equipment, to score simulated thermonuclear bombing of cities in the continental United States.

Chapter 5

Bogie Exchange

Bogie exchange is a system for operating railway wagons on two or more gauges to overcome difference in the rail gauge. To perform a bogie exchange, a car is converted from one gauge to another by removing the chassis containing the wheels and axles of the car, and installing a new chassis with differently spaced wheels. It is generally limited to wagons and carriages, though engines can be exchanged if more time is available.

Bogies exchange operation in Ussuriisk (near Vladivostok) at the Chinese–Russian border

Bogie change station at Chop, Ukraine station, Ukraine which connects to Hungary and Slovakia

Wagons and carriages

Bogie wagons can have their gauge changed by lifting them off one set of bogies and putting them back down again on another set of bogies. The pin that centres the bogies and the hoses and fittings for the brakes must be compatible. There needs to be a generous supply of bogies of each gauge to accommodate the ebb and flow of traffic.

The bogies and wagons also need to have standardized hooks, etc, where they may be efficiently lifted.

Four-wheel wagons are not suitable for gauge change.

Engines

Steam

Steam engines can be designed for more than one gauge, by having, for example, reversible wheel hubs that suit two alternative gauges. This was done in the 1930s and beyond in Victoria for possible gauge conversion, though no engines were ever converted in this manner other than one heritage engine (R766). Some 1,000 mm (3 ft 3 $\frac{3}{8}$ in) Garratt locomotives of East Africa were designed for easy conversion to 3 ft 6 in (1,067 mm) Cape gauge, though again none ever were.

In the southern United States, some steam locomotives built by Baldwin were designed for easy conversion from 1,524 mm (5 ft) to 1,435 mm (4 ft 8 $\frac{1}{2}$ in).

Diesel

Diesel locomotives have bogies like wagons and carriages, only with more cables for the traction motors and take a little longer to convert. In Australia, some classes of diesel locomotives are regularly gauge-converted to suit traffic requirements on the 1,435 mm (4 ft 8 $\frac{1}{2}$ in), 1,600 mm (5 ft 3 in) and 1,067 mm (3 ft 6 in) networks.

Since the 1,067 mm (3 ft 6 in) networks are not all connected to each other, being separated by deserts or lines of other gauges, the are bogie-exchanged or piggybacked on road or rail vehicles when transferred between these networks.

Raising or lowering

Raise

The simplest way to carry out bogie exchange is the lift the wagons off the bogies and replace them back on new bogies. This may require the wagons in a train to be uncoupled, and continuous brakes disconnected. As the bogies are swung out of the way, they sway, which wastes time settling them down.

Lower

A cleverer way of carrying out bogie exchange is to lower the bogies onto a trolley in a pit, after which the trolleys are rolled out of the way and others return. This keeps the train couplings and continuous brakes connected. In addition, the bogies never need leave a solid surface, so that they can be wheeled in and out more quickly. This method was used at Dry Creek railway station, Adelaide.

International

Australia

Between 1961 and 1995, Australia had five bogie exchange centres, which opened and closed as gauge conversion work proceeded. The gauges served were 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,600 mm (5 ft 3 in), though the 1,067 mm (3 ft 6 in) Queensland did acquire 100 bogie-exchange compatible QLX wagons just in case. All the wagons involved had wagon codes ending in "X", such as VLX.

The centres were:

- Dynon, Melbourne, Victoria
- Wodonga near Albury on state border.
- Port Pirie, South Australia
- Peterborough, South Australia
- Dry Creek, Adelaide, South Australia - the youngest and most modern.

The busiest facility was that at Dynon, in a typical year (1981–82) 24,110 wagons were bogie exchanged, an average of 66 per day. This was done by one shift of 18 men, compared with the 100 men required if the same amount of freight was transferred wagon to wagon.

Belarus

- Brest, Belarus – between 1,520 mm (4 ft 11 $^5⁄_6$ in) and 1,435 mm (4 ft 8 $^1⁄_2$ in) at the border to Poland

Bolivia

Bogie exchange used between 762 mm (2 ft 6 in) and 1,000 mm (3 ft 3 $^3⁄_8$ in) gauge on the Ferrocarril de Antofagasta a Bolivia Railway.

Canada

- Between 1,435 mm (4 ft 8 $^1⁄_2$ in) Standard gauge and the 3 ft 6 in (1,067 mm) gauge of the former Newfoundland Railway (Terra Transport) at Port aux Basques

China

A bogie exchange station exists at the Chinese border to Mongolia. Both the Moscow-Beijing passenger train (Trans-Siberian) and freight trains get their bogies exchanged. Mongolia has Russian gauge 1,520 mm (4 ft 11 $^5⁄_6$ in), China has 1,435 mm (4 ft 8 $^1⁄_2$ in).

Finland

A bogie exchange station exists in the Port of Turku with a short stretch of 1,435 mm (4 ft 8 $^1⁄_2$ in) gauge railway. Freight cars get their bogies exchanged. SeaRail train ferries go from Germany and Sweden. They carry no passenger trains, and passengers must walk by foot to Turku Harbour railway station opposite the ferry terminals. Finland has 1,524 mm (5 ft) broad gauge.

Iran

- Jolfa - c1950, between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,520 mm (4 ft 11 $\frac{5}{6}$ in) (Russian gauge)
- Sarakhs - c1990, between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,520 mm (4 ft 11 $\frac{5}{6}$ in) (Russian gauge)
- Zahedan - proposed 2008, between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,676 mm (5 ft 6 in) (Indian gauge)

Kazakhstan

- Druzhba, KZ - Alashankou, CN between 1,520 mm (4 ft 11 $\frac{5}{6}$ in) and 1,435 mm (4 ft 8 $\frac{1}{2}$ in).

North Korea

- Tumangan, North Korea – between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,520 mm (4 ft 11 $\frac{5}{6}$ in) (Russian gauge) at the border to Russia.

The bogies of the direct sleeping car Moscow - Pyongyang, which runs twice monthly, are exchanged here.

Peru

- Between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) Standard gauge and 3 ft (914 mm) on the Ferrocarril Central Andino, including locomotives

Romania

- Between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,520 mm (4 ft 11 $\frac{5}{6}$ in) at Vadul Siret between Romania and Ukraine
- Between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,520 mm (4 ft 11 $\frac{5}{6}$ in) at Ungheni, Iași between Romania and Moldova

Russia

- Zabaikalsk (450 km from Chita) with China
- Grodekovo (116 km from Ussuriisk and 224 km from Vladivostok) with China
- Khasan - North Korea (315 km from Vladivostok).
- Kholmsk, Sakhalin Island. The bogie exchange is necessary to enable Russian mainland cars to run on the Sakhalin railways, which use the Japanese gauge of 1,067 mm (3 ft 6 in).

Spain

- At Irun, between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,668 mm (5 ft 5 $\frac{2}{3}$ in) (Iberian gauge)
- At Portbou, between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) and 1,668 mm (5 ft 5 $\frac{2}{3}$ in)

Tunisia

- Between 1,435 mm (4 ft 8 $\frac{1}{2}$ in) Standard gauge and 1,000 mm (3 ft 3 $\frac{3}{8}$ in) (meter gauge), including locomotives

Ukraine

- Chop, Ukraine – between 1,520 mm (4 ft 11 $\frac{5}{6}$ in) (Russian gauge) and 1,435 mm (4 ft 8 $\frac{1}{2}$ in) at the border to Hungary and Slovakia
- Jagodin, Ukraine – between 1,520 mm (4 ft 11 $\frac{5}{6}$ in) (Russian gauge) and 1,435 mm (4 ft 8 $\frac{1}{2}$ in) at the border to Poland

Transfer time

Bogie exchange conversion times were:

- Dynon, Australia - one wagon every 7.3 minutes.
- Zabaykalsk - one a rail car takes 5–6 hours.
- Erenhot - one a rail car takes 5–6 hours.

Variable Gauge Axles

Variable Gauge Axles also called Automatic Track Gauge Changeover System is a newer and faster development than bogie exchange. While Bogie Exchange is "obvious" and brute force, VGA / ATGCS is "subtle, hidden" and elegant. The SUW 2000 ATGCS requires a change over track about 20 m long, with a shed if there is snow compared to a small marshalling yard required by bogie exchange.

Chapter 6

Coupling (Railway)

Knuckle (AAR Type "E") couplers in use

ICE coupler

A **coupling** (or a **coupler**) is a mechanism for connecting rolling stock in a train. The design of the coupler is standard, and is almost as important as the railway gauge, since flexibility and convenience are maximised if all rolling stock can be coupled together.

The equipment that connects the couplings to the rolling stock is known as the **draft gear**.

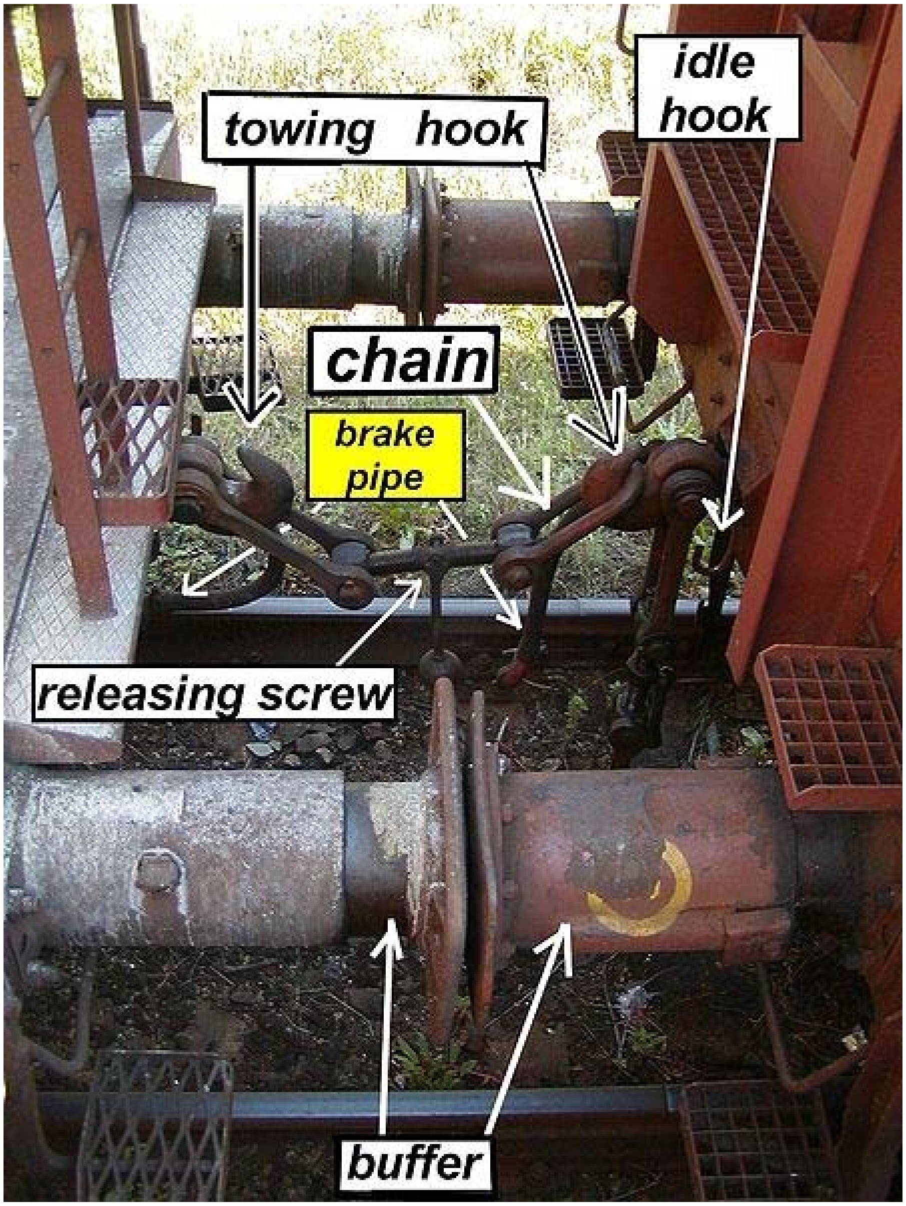
Nomenclature

The different types of coupling do not always have formal or official names, which makes descriptions of the couplings in use on any railway system problematic.

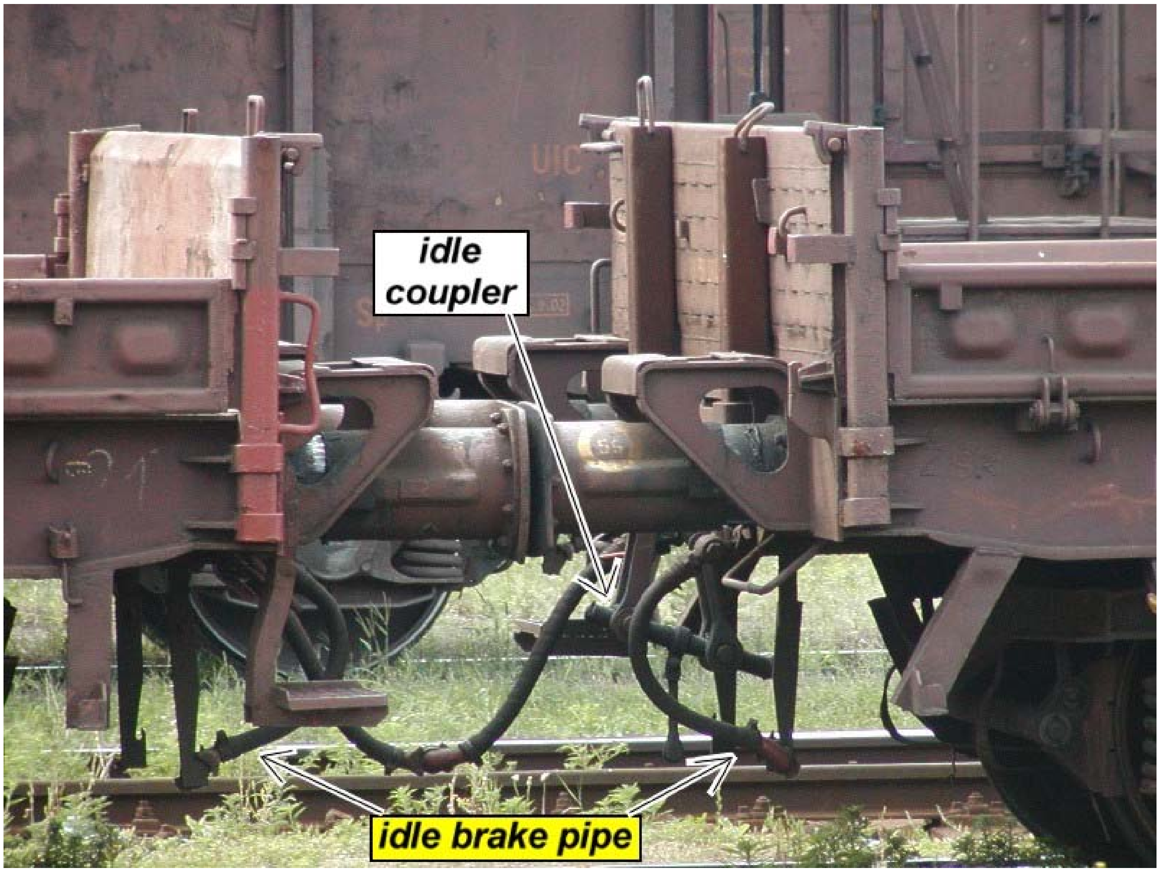
Buffers and chain

Traditional buffer-and-chain coupler

Two cars coupled



Chain coupler detail (train in shunting mode)



Cars coupled in ride mode

The standard type of coupling on railways following the British tradition is the buffer and chain coupling used on the pioneering Liverpool and Manchester Railway of 1830. These couplings followed earlier tramway practice but were made more regular. The vehicles are coupled by hand using a hook and links with a turnbuckle-like device that draws the vehicles together. In Britain, this is called a *screw coupling*. Vehicles have buffers, one at each corner on the ends, which are pulled together and compressed by the coupling device. This arrangement limits the slack in trains and lessens shocks. In contrast, Janney couplers encourage comparatively violent encounters in order to engage the coupling fully. The earliest buffers were fixed extensions of the wagon frames, but later spring buffers were introduced.

Inefficient and slow, the European system is relatively unsafe because it requires manual coupling between vehicles, exposing workers to the risk of being crushed. However, there is no need for the worker to go between vehicles while they are moving, which is an improvement over the link-and-pin types.

This coupling type is the standard in European countries (except the former Soviet Union, where the SA-3 automatic coupler is used). Coupling is done by a worker, who must climb between the cars. First he turns a releasing screw (an aid with two opposite windings, and it does not uncouple the train itself) to the loose position, and then he can hang the chain on the hook. After hanging the chain on the towing hook the releasing screw must be turned to the tight position. When the coupler is uncoupled, it must be hung on the idle hook to prevent damage to itself or the brake pipes. Only shunting is permitted with a dangling chain. Disconnected brake pipes must be hung on hooks. (The picture shows two coupled cars, with a single brake pipe.)

The hooks and chain hold the carriages together, while the buffers keep the carriages from banging into each other so that no damage is caused. The buffers can be "dumb" or spring-loaded. That means there are no run-in forces on the coupler. The other benefit compared with automatic couplers is that its lesser slack causes smaller forces on curves; there is a lower probability of a broken coupler in a curve than with automatic couplers. The disadvantage is the smaller mass of the freight that can be hauled by that coupler (maximum 3,000 t/6,613,868 lb).

Early rolling stock was often fitted with a pair of auxiliary chains as a backup if the main coupling failed. This made sense before the fitting of continuous fail-safe braking systems.

On railways where rolling stock always pointed the same way, the chain might be mounted at one end only, as a small cost- and weight-saving method.

On German and Scandinavian railways, the left buffer is flatter than the right one, which is slightly more rounded. This provides better contact between the buffers than would be the case if both buffers were slightly rounded.

Three-link couplings

A peculiarly British institution was the "loose-coupled" freight train. This used three-link chain couplings with no means of drawing the wagons together: since such trains were not fitted with an automatic through-train braking system there were no pipes to connect between the vehicles. The couplings in the train were kept taut by the last vehicle of the train being a heavily ballasted guard's van with its brakes set slightly on. This helped prevent snapped couplings. Such trains travelled at low speeds and were phased out in the 1970s.

An improvement on this is the "Instanter" coupling, in which the middle link of a three link chain is specially shaped so that when lying "prone" it provides enough slack to make coupling possible, but when this middle link is rotated 90 degrees the length of the chain is effectively shortened, reducing the amount of slack without the need to wind a screw. The closeness of the coupling allows the use of inter-vehicle pipes for train brakes. It also has the advantage that it can be operated entirely from the side of the wagons using a shunter's pole and is therefore safer when shunting work is under way. These couplings are still prevalent in UK freight trains today.

Buffers-and-chain on the narrow gauge

Perhaps because of the buffer-locking problem occasioned by sharp curves – and Carl Pihl's successful promotion of the single-buffer Norwegian coupler that he designed to overcome this – conventional buffers-and-chain coupling is rarely employed on narrow-gauge systems: notable exceptions being the railway networks of Senegal/Mali and Côte d'Ivoire/Burkina Faso in Africa, and Queensland and Tasmania in Australia.

Problems with buffers and chain

Buffer-locking

The buffers and chain coupling system has a maximum load much less that of the Janney coupling. Also, on sharp reverse curves, the buffers can get buffer-locked by slipping over – and onto the back of – an adjacent buffer. Although careful track design makes this occurrence rare, an accident at a Swiss station in the 1980s was caused by buffer-locked wagons. Buffer-lock could be caused on the very sharp turnouts by the older, rounded buffers. The newer buffers are rectangular and they are wider than they are tall. They are not so flat, so they rarely cause buffer-locking.

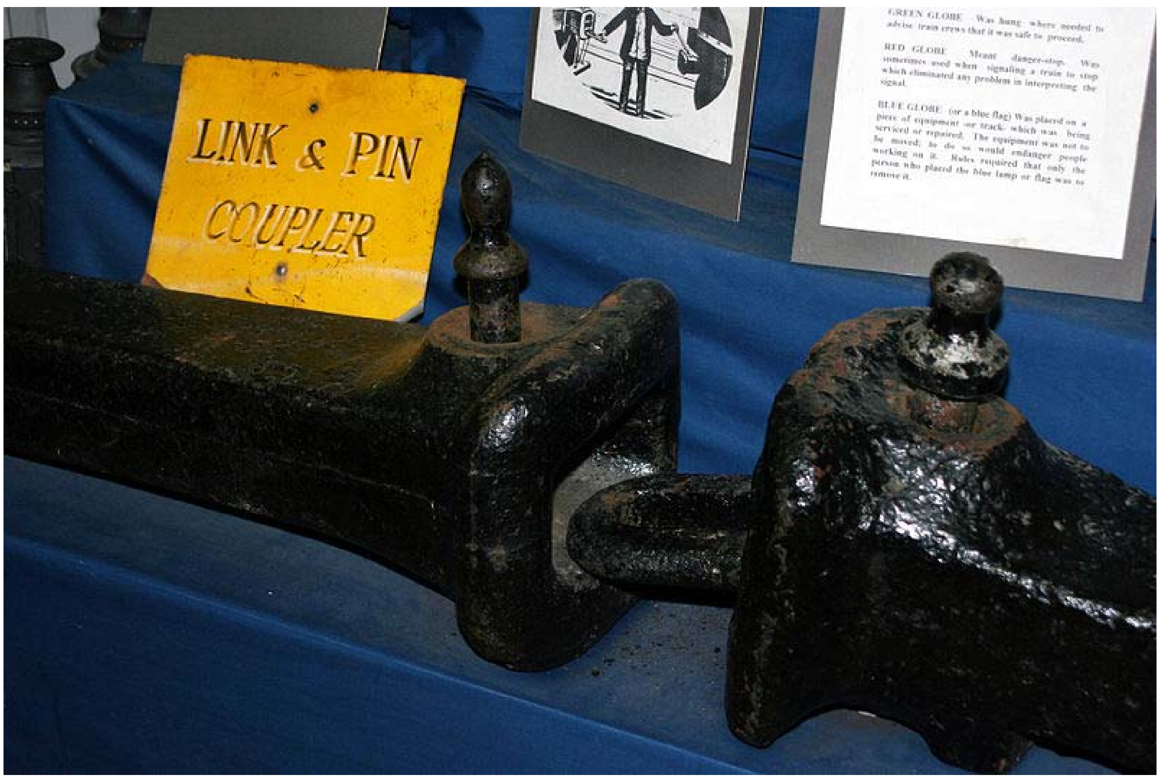
Variation with gauge

The narrow gauge "buffer-&-chain" coupler, called *Balancierhebelkupplung*

The width between the buffers tends to increase as the gauge increases, so that if wagons are changed from one gauge to another, the buffers will no longer match. This occurs because the buffers are originally extensions of the frames, which are spaced according to the gauge. Conversely, as gauge reduces, the distance between the buffers reduces also. The height of the buffers is usually lower on narrow gauge railways, corresponding to the generally lower height of the rolling stock.

On some narrow-gauge lines in Europe a simplified version is used, consisting of a single central buffer with a chain underneath. Sometimes there are two chains, one on each side of the coupler. The chain usually contains a screw-adjustable link to allow close coupling. On sharp curves, a single centre buffer is less likely to be subject to buffer-locking.

Link and pin



A link-and-pin coupler.

The link-and-pin coupling was the original style of coupling used on American railways, surviving on forestry railways after others converted to Janney couplings. While simple in principle, the link-and-pin coupling suffered from a lack of standardisation regarding size and height of the links.

The link-and-pin coupler consisted of a tubelike body that received an oblong link. During coupling, a railworker had to stand between the cars as they came together and guide the link into the coupler pocket. Once the cars were joined, the employee inserted a pin into a hole a few inches from the end of the tube to hold the link in place. This procedure was exceptionally dangerous and many brakemen lost fingers or entire hands when they did not get their hands out of the way of the coupler pockets; many more were killed as a result of being crushed between cars or dragged under cars that were coupled too quickly. Brakemen were issued with heavy clubs that could be used to hold the link in position, but many brakemen would not use the club, and risk injury.

The link-and-pin coupler proved unsatisfactory because:

- It made a loose connection between the cars, with too much slack action.
- There was no standard design, and train crews often spent hours trying to match pins and links while coupling cars.
- The links and pins were often pilfered (due to their value as scrap metal), resulting in substantial replacement costs. John H. White suggests that the railroads considered this to be more important than the safety issue at the time.
- Crew members had to go between moving cars during coupling, and were frequently injured and sometimes killed.
- Eventually, railroads wished to operate trains that were heavier than the link-and-pin system could cope with.

An episode of the 1960s TV series *Casey Jones* was devoted to the problems of link-and-pin couplings.

The Miller Hook and Platform

The link and pin was replaced in U.S. passenger car usage during the latter part of the 19th century by the assemblage known as the Miller Platform, which included a new coupler called the Miller Hook. The Miller Platform (and hook coupler) was used for several decades before being replaced by the Janney coupler.

Norwegian

Norwegian coupling fitted to an ex-WDLR Alco from the Froissy Dompierre Light Railway

Norwegian coupling in Uganda

Norwegian (or meat chopper) couplings consist of a central buffer with a mechanical hook that drops into a slot in the central buffer. The Norwegian is found only on narrow gauge railways of 1,067 mm (3 ft 6 in) or less, such as Western Australian Government Railways, the Ffestiniog Railway and the Welsh Highland Railway, where low speeds and reduced train loads allow a simpler system. New Zealand Government Railways, during the 1970s, developed an extremely large and heavy-duty version of the chopper coupler. These were first applied to a fleet of GE locomotives (class Dx) that had arrived from the U.S. with auto couplers, however they were converted once it was decided that these locomotives would operate on other than just the North Island Main Trunk express freight trains. On railway lines where rolling stock always points the same way, the mechanical hook may be provided only on one end of each wagon. This was the situation on the Lynton & Barnstaple (L&B), a narrow gauge line in Devon, England, and still applies to railways in New Zealand. Similarly, the hand brake handles may also be on one side of the wagons only.

Norwegian couplings are not particularly strong, and may be supplemented by auxiliary chains. The L&B originally used side chains in conjunction with Norwegian couplers, but these were found to be unnecessary with the slow speeds employed (10–15 mph/16–24 km/h) and were removed within a year or so of the line opening in 1898.

The Pichi Richi Railway in South Australia uses Norwegian couplers as its standard, and converts Janney coupler to Norwegian as required. The slot in the "buffer beam" where the coupler protrudes appears to be about the same for both types of couplers. As a museum, it is appropriate to use the older type of coupling.

Not all Norwegian couplings are compatible with one another as they vary in height, width, and may or may not be limited to one hook at a time.

Bell

Automatic couplers

There are a number of automatic train couplings, most of which are mutually incompatible.

Janney (AAR) coupler

Later Master Car Builders Association coupler, now AAR (Association of American Railroads) coupler; also known as knuckle coupler and alliance coupler.

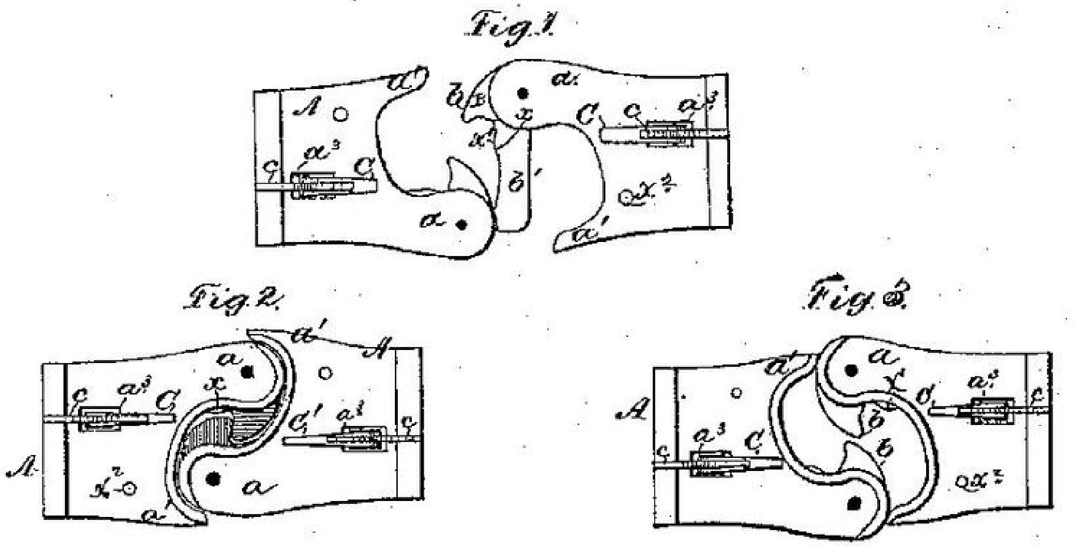


Diagram of the top view of Janney's coupler design as published in his patent application in 1873.

The knuckle coupler or Janney coupler was invented by Eli H. Janney, who received a patent in 1873 (U.S. Patent 138,405). It is also known as a "buckeye coupler", notably in the United Kingdom, where some rolling stock (mostly for passenger trains) is fitted with it. Janney was a dry goods clerk and former Confederate Army officer from Alexandria, Virginia, who used his lunch hours to whittle from wood an alternative to the link and pin coupler. The term Buckeye comes from the nickname of the US state of Ohio, the "Buckeye state" and the Ohio Brass Company which originally marketed the coupling.

In 1893, satisfied that an automatic coupler could meet the demands of commercial railroad operations and, at the same time, be manipulated safely, the United States Congress passed the Safety Appliance Act. Its success in promoting switchyard safety was stunning. Between 1877 and 1887, approximately 38% of all railworker accidents involved coupling. That percentage fell as the railroads began to replace link and pin couplers with automatic couplers. By 1902, only two years after the SAA's effective date, coupling accidents constituted only 4% of all employee accidents. Coupler-related accidents dropped from nearly 11,000 in 1892 to just over 2,000 in 1902, even though the number of railroad employees steadily increased during that decade.

When the Janney coupling was chosen to be the American standard, there were 8,000 patented alternatives to choose from. The only significant disadvantage of using the AAR (Janney) design is that sometimes the drawheads need to be manually aligned.

AAR Type "E" coupler serving as a tow hitch on a mobile crane. Pulling up on the link at the rear releases the knuckle allowing uncoupling.

The AAR coupler is used in Canada, the United States, Mexico, Japan, Australia, South Africa, Saudi Arabia, Cuba, Chile, Brazil, China and elsewhere. Among its features:

- Maximum tonnage as high as 32,000 metric tons (71,000,000 lb) such as on the Fortescue Railway.
- Minimum Ultimate Tensile Strength:
    - Grade E Knuckles:650,000 pounds-force (2.9 MN)
        - Only Grade C or Grade E Knuckles are permissible in interchange service.
    - Grade E Coupler Bodies:900,000 pounds-force (4.0 MN)

- Many AAR Coupler designs exist to accommodate requirements of various car designs, but all are required to have certain dimensions in common which allow for one design to couple to any other.
    - Lighter weight railways, especially those of narrow gauge or with no need for Interchange (freight rail) sometimes use smaller (three-quarter- or half-size) versions of the AAR coupling.
- AAR couplers are always right-handed.
- Required Coupler Heights
    - Empty Cars: 33.5 inches (85 cm) +/- 1-inch (2.5 cm)
    - Loaded Cars: 32.5 inches (83 cm) in +/- 1-inch (2.5 cm)
- AAR couplers are uncoupled by lifting the coupling pin with a lever at the corner of the car. This pin is locked when the coupler is under tension, so the usual uncoupling steps are to compress the coupling with a locomotive, lift and hold up the pin, then pull the cars apart. Side operated variants are called the "Sharon coupler" or "Buckeye coupler".
- Trains fitted with AAR couplers can accommodate heavier loads than any other type of coupler. Thus the heaviest coal trains in New Zealand have AAR couplings even though the remainder of the fleet has the "meat chopper" kind. Also, long-distance freight trains in North America are commonly more than 1-mile (1.6 km) long, whereas this is not seen in Europe, where most freight trains still use the buffers and chain system.

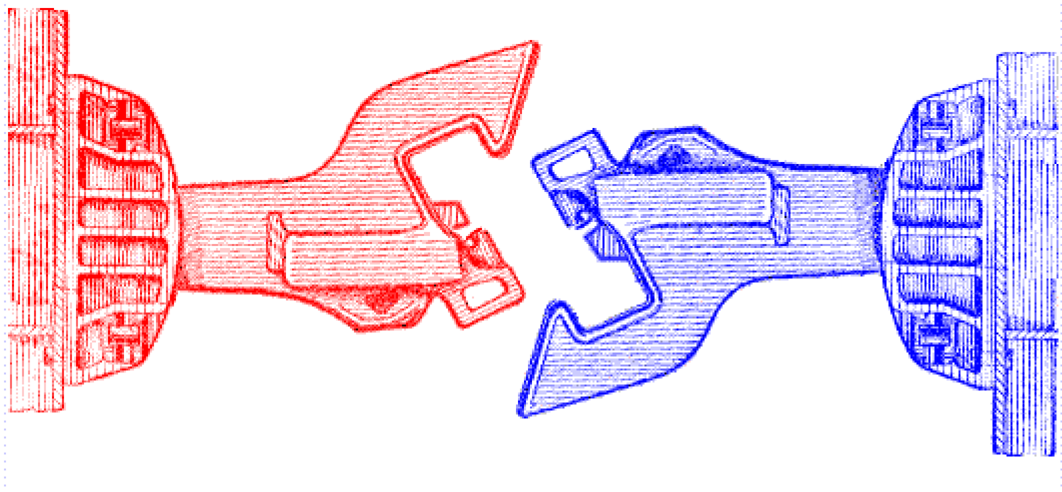
Changes since 1873

Standard AAR Type E couplers performing their function in a freight train.

The AAR coupler has withstood the test of time since its invention, and has seen only minor changes:

- The current AAR contour dates back to the Master Car Builders Association (MCBA) coupler.
- Buckeye coupler, a side operated version of the MCBA coupler
- Type "E" coupler, the original (plain) AAR coupler, derived from the Master Car Builders Association coupler.
- Type "F" coupler, a "tooth and socket" or "tightlock" variation to prevent accidents, derailments and wrecks from uncoupling the couplers. The "tooth" on a loose coupler could puncture any tank car or other car carrying hazardous materials. Variations on the AAR type "F" coupler have been devised to provide extra protection, in case of derailments and train wrecks, to cars routinely carrying sensitive or hazardous loads. These variations of type "F" couplers, generally involving "shelves", remain fully compatible with standard AAR couplers, but tend to keep derailments and collisions from uncoupling the cars (thereby preventing the "tooth" of the couplers from piercing the ends of the cars).
- The APTA (former AAR) standard type "H" coupler, a "tooth and socket" or "tightlock" variation used mostly, if not exclusively, on passenger cars. The Type "H" coupler is now under the supervision of the APTA (American Public Transportation Association)
- Types "F" and "H" couplers are also known as tightlock couplings.
- "pads" to reduce slack on passenger trains.
- improvement to castings, etc. to increase maximum trailing load.
- rotating-shaft couplers (type "F") introduced for use in rotary car dumpers such as on the Pilbara railways.
- narrow gauge railways such as the Victorian Puffing Billy Railway use a miniature version of the AAR coupler.

SA3 coupler



The simplified scheme of the SA-3 automatic couplers.

The Russian SA3 coupler works according to the same principles as the AAR coupler but is incompatible, it was introduced during the rebuilding of the railway network in Soviet Union after the Second World War and have since been used on the whole broad gauge network, including Finland and Mongolia. It is also used on the normal gauge networks of Iraq and on Malmbanan in Sweden for ore trains.

- Russian trains are rarely longer than about 750 m (2,460 ft) and rarely exceed a maximum tonnage about 6,000 t (13,000,000 lb), so it is not clear what potential load these couplings are capable of. The trains on Malmbanan are about 8,000 t (18,000,000 lb).
- The force to break the SA-3 coupler is about 300 tonnes-force (2.9 MN; 660,000 lbf).
- The maximum allowed tractive effort to the SA-3 is limited to 135 tonnes-force (1.32 MN; 298,000 lbf) by Russian white papers.
- The proposed European automatic coupler is compatible with the Russian coupler but with automatic air, control and power connections. Implementation is permanently delayed except for a few users.

Unicoupler/Intermat

Unicoupler has been developed by Knorr company from Germany in the 1970s and is widely used in Iran in freight cars. this type of coupler is compatible by SA-3 and willison couplers. The Unicoupler is also known as AK69e. The Unicoupler was the West-European development, it was developed in parallel with a compatible East-European couterpart, the Intermat coupler.

C-AKv

The C-AKv coupler is a newer compact willison coupler developed by Faiveley Transport. It is mechanical fully compatible to the SA-3 coupler and the Unicoupler and if additional buffers are mounted it can be coupled with the conventional European screw coupling too.

Other

- Scharfenberg coupler used on electric passenger trains - connects brake and controls.

    - Maximum tonnage under 1,000 t (2,200,000 lb).

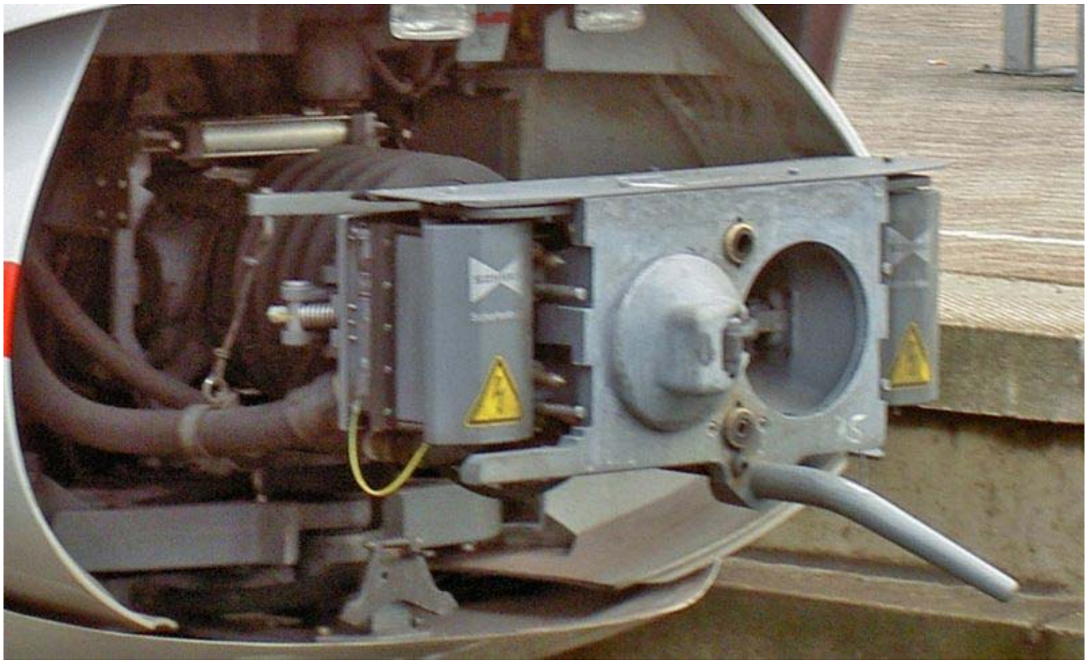
Multi-Function Couplers

MFCs are 'fully automatic' couplers that make all connections between the rail vehicles (mechanical, air brake and electrical) without human intervention, in contrast to autocouplers which just handle the mechanical aspects. The majority of trains fitted with these types of couplers are multiple units, especially those used in mass transit operations.

There are a few designs of fully automatic couplers in use worldwide, including the Scharfenberg coupler, various knuckle hybrids (such as the Tightlock, used in the UK), the wedgelock coupling, Dellner couplings (similar to Scharfenberg couplers in appearance), BSI coupling and the Schaku-Tomlinson Tightlock coupling.

There are a number of other automatic train couplings similar to the Scharfenberg coupler, but not necessarily compatible with it. Older US transit operators continue to use these non-Janney electro-pneumatic coupler designs and have used them for decades.

Dellner manufactured Scharfenberg



Scharfenberg

BSI

APTA, Type "H", Tightlock coupling

Wedgelock

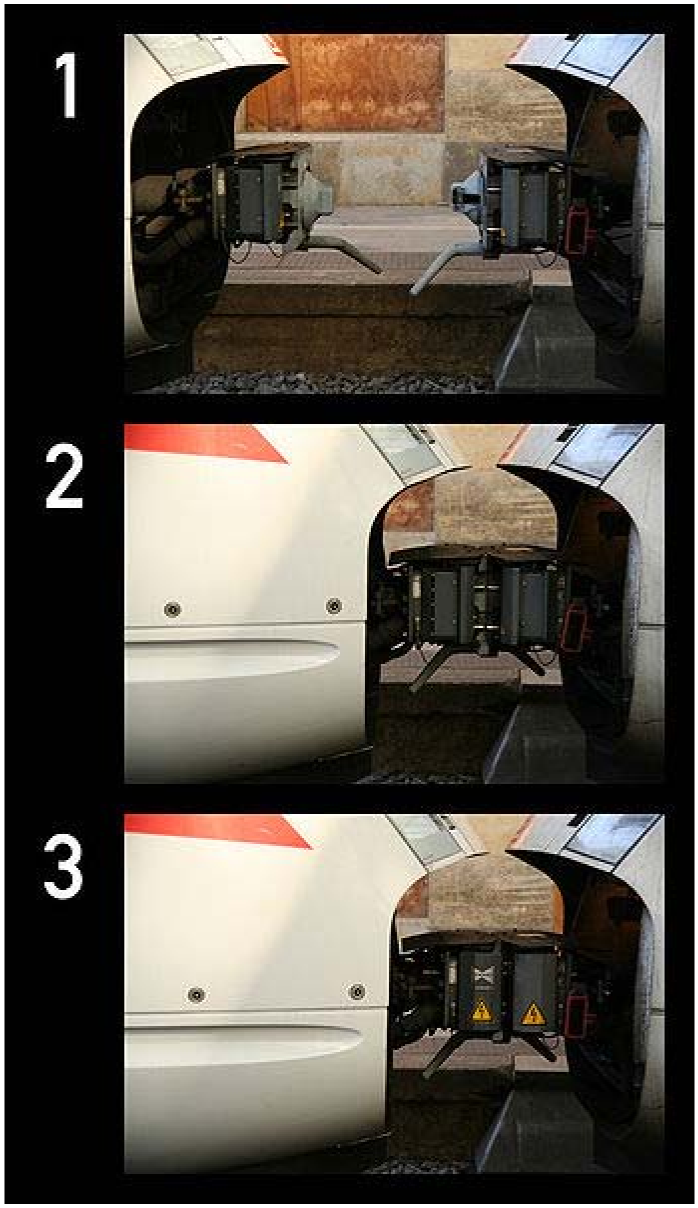
Budd Pin and cup coupler

Westinghouse H-2 MU coupler

The Westinghouse coupler is used on the R62 and R62A train of the 7, 1, and 3 line, with a Scharfenberg with no power port at the front of the locomotive. The other cars use either a permanent drawbar, or a Westinghouse coupler, but all with Schaku.

Scharfenberg coupler

The MY locomotive, normally screw-coupled, has a Scharfenberg coupler mounted for transporting Lint 41 DMU's



Two ICE-T trains coupling. In picture #1 both trains are ready to be coupled, picture #2 shows the trains joined mechanically, picture #3 shows the trains coupled mechanically and electrically.

The Scharfenberg coupler (German: *Scharfenbergkupplung* or *Schaku*) is probably the most commonly used type of fully automatic coupling. Designed in 1903 by Karl Scharfenberg in Königsberg, Germany (today Kaliningrad, Russia), it has gradually spread from transit trains to regular passenger service trains, although outside Europe its use is generally restricted to mass transit systems. The Schaku coupler is superior in many ways to the AAR (Janney/Knuckle) coupler because it makes the electrical and also the pneumatic connections and disconnections automatic. However there is no standard for the placement of these electro-pneumatic connections. Some rail companies have them placed on the sides while others have them placed above the mechanical portion of the Schaku coupler. The main disadvantage to the Scharfenberg coupler is its low maximum tonnage, which makes it unsuitable for freight operations.

Small air cylinders, acting on the rotating heads of the coupler, ensure the Schaku coupler engagement, making it unnecessary to use shock to get a good coupling. Joining portions of a passenger train can be done at very low speed (less than 2 mph/3.2 km/h in the final approach), so that the passengers are not jostled about. Rail equipment manufacturers such as Bombardier offer the Schaku coupler as an option on their mass transit systems and their passenger cars and locomotives. In North America all the trains of the Montreal Metro are equipped with it, as are new light rail systems in Denver, Baltimore and New Jersey. It is also used on light rail vehicles in Portland, Minneapolis, the Vancouver Skytrain, and the Scarborough RT in Toronto. It also equips all the dedicated rolling stock used for the shuttle services in the Channel Tunnel.

- Maximum tonnage under 1,000 t (2,200,000 lb).

United Kingdom

Due to the rush to dieselise and electrify, the United Kingdom ended up with a variety of incompatible couplings and electrical connections. The latter were categorised as yellow triangle, blue square, and so on.

Automatic Buffing Contact Coupler

- Automatic Buffing Contact Coupler

Other

Dellner

Dual couplings and match wagons

Coupling adapter for use between AAR couplers on locomotives and automatic couplers on commuter rail multiple units at New York's Pennsylvania Station. The adapter is seen from the bottom

If a wagon with one coupling system needs to be coupled to wagons with another coupling type there are two solutions. This may be needed when taking metro rolling stock from its manufacturer to the city where it is to be used:

- use a match wagon(s) which has different couplings at either end.
- use a coupling adaptor (such as illustrated).

Only some kinds of couplings coexist on the end of a wagon at the same time, because amongst other reasons they need to be at the same height. For example, in the Australian state of Victoria, engines had the AAR coupler, with buffers, and the chain mounted on a lug cast into the AAR coupler.

A match wagon or match truck (also known as a barrier vehicle / wagon in Britain and Transition Car in the United States) has different kinds of couplings at each end. If a pair of match wagons is used, a rake of wagons using coupling A can be inserted into a train otherwise using coupling B.

A coupling adaptor or compromise coupler might couple to an AAR coupling on a wagon, and present, for example, a meatchopper coupler or rapid transit coupler to the next wagon. Such an adaptor might weigh 100 kg (220 lb).

Dual coupling

It is possible to mount both buffers and chain and knuckle couplers on the same car, provided that one can swing out of the way. Alternatively, either a lug to hold the chain is cast in the body of the coupler or a chain is mounted on top of the coupler. This is also done with an SA3 coupler built by SAB WABCO.

Locomotives and some freight cars of the Indian Railways are fitted with a 'transition coupler' that incorporates a screw coupling within a knuckle coupler: the knuckle coupler remains in position and does not swing away when not in use. The screw coupling is mounted on a lug within the knuckle coupler. Most Indian freight cars use the knuckle coupler alone, without buffers, whereas passenger coaches almost exclusively use screw couplers and buffers. Exceptions are the new LHB coaches imported from Europe, and a few other makes of carriages converted to use knuckle couplers.

A Finnish locomotive with dual coupling

Some Russian locomotives and wagons have buffers together with the central coupler. When coupling to Finnish equipment, a short chain with a block that fits in the central coupler is placed on the Russian side, backing up and compressing the buffers so that the chain can be laid on the hook. (That is also the common way of coupling locomotives to or from wagons, faster than unscrewing the link.)

British-style dual buffer-and-chain/automatic coupler with knuckle swung out of the way

British locomotive-hauled passenger carriages adopted a dual coupling system in the 1950s. They have retractable buffers and a central Buckeye automatic knuckle coupler that lowers to reveal a hook for a screw-type chain coupling. When in use, a pin through the buckeye shank rests in the conventional hook. No chain is provided on dual-coupled vehicles, since the chain on the other vehicle can be used where knuckle couplers are not present. Inter-stock coupling was with the automatic coupler (with the buffers retracted), while connection to the locomotive was with the buffer-and-chain system with a screw coupler. Today this dual coupling system has been adopted for all loco-hauled passenger trains in Great Britain to allow faster shunting operations.

If worst comes to worst one might use a rope to join two wagons together, as might happen if one of the couplers breaks in service. This formed a plot point in the British comedy film The Titfield Thunderbolt, where a rope had to be used to connect a commandeered antique locomotive to its train. The rope subsequently snapped, leaving the train stranded.

Sets of carriages

Automatic couplers like the Janney are safer in a collision because they help prevent the carriages telescoping. British Rail therefore decided to adopt a Janney variant for its passenger carriages, with the coupler able to swing out of the way for coupling to engines with the traditional buffer and chain system.

In New South Wales, sets of carriages were permanently coupled with a fixed bar, since the carriages were disconnected only at the workshops. Freight cars are sometimes coupled in pairs or triplets, using bar couplings in between.

Articulated sets of carriages or wagons share the intermediate bogies, and have no need for couplings in the intermediate positions.

Coupler conversion

From time to time, a railway decides that it needs to upgrade its coupling system from one that is proving unsatisfactory, to another that meets future requirements. This can be done gradually, which can create lots of problems with transitional incompatibilities, or overnight, which requires a lot of planning.

Japan

Japan converted its British-derived buffer and chain couplings to the American Janney coupling over a period of a few days in the early 1920s, after considerable preparation. Today, most (if not all) EMUs including high-speed Shinkansen trains, and some DMUs use the Shaku-Thomlinson type coupling system, while locomotive-hauled trains use the Janney coupling and Tightlock coupling system.

Australia

Australia, with its breaks of gauge, has always had different couplers on different systems, and has generally adopted gradual conversion. Conversion to the Janney coupling is now virtually complete. Commonwealth Railways started with Janney couplings on its standard gauge Trans-Australian line, and some railways, like the former Victorian Railways and the Queensland Railways, used dual couplers. Older couplers remain on Heritage railways.

Europe

The European network has traditionally been formed of many independent national railway networks with buffer and chain used near universally to allow the interchange of rolling stock. The European Union Technical Specifications for Interoperability (TSIs) for high-speed passenger rolling stock mandate the use of Scharfenberg Type 10-compatible couplings. The Type 10 includes "horns" to aid coupling on curves and include a function to provide standardised automatic air-brake connections; the coupling horn is often visible poking out at the front of the nose of high-speed trains.

For European freight, the TSIs mandate buffer and chain couplings at specified heights. The European system links to the former Soviet Russian-gauge network, where SA3 automatic couplers are used. Some research has been undertaken to chose an automatic freight coupler compatible with the Soviet one, but owing to widescale replacement cost, no action has been taken to implement the conversion, except for some trial installations. In many heavy-haul applications, such as for coal and iron ore, either US AAR-type couplers or Soviet SA-3 couplers are used. Conversion is made harder to justify because the existing buffer and chain coupling is almost universal.

Meanwhile, drawgear of new rolling stock is being built at a height suitable for conversion. The proposed European freight coupling is compatible with the SA3 coupler but adds integrated air and electrical connections. This standard would need to be revised to allow for the unforeseen development of electronically controlled pneumatic brakes.

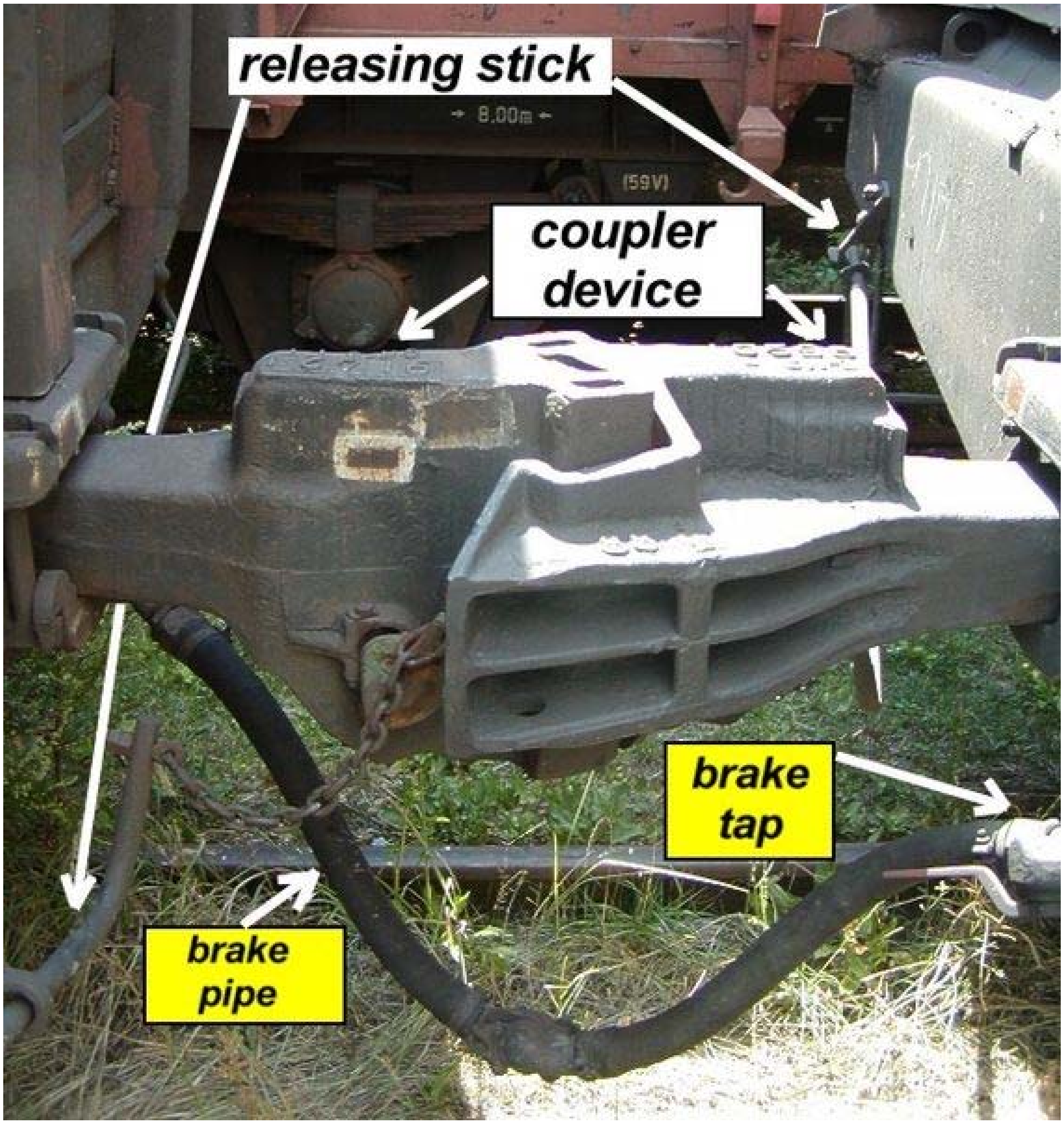
United States

Once Congress passed the Safety Appliance Act mandating conversion from the link and pin coupler to the Janney coupler, railroads in the United States had only a few years to implement the change. The railroads in North America, except for mass transit, form one unitary system, and uniformity of couplers is important for smooth interchange of rolling stock.

Latin America

Railways in Central and South America are fragmented by gauge, geography, and financial and technical heritage. While some systems have adopted the American Janney coupler, others retain the British buffer and hook (buffer and chain) coupler.

Soviet Union and successor states



Detail of the SA-3 coupler in coupled mode

SA-3 coupler, uncoupled

Russia and Central Asia used buffer and chain couplings, albeit with possibly wider centres for the buffers, until conversion to automatic SA3 couplers. The SA3 coupler was invented in 1932. Some wagons were equipped with SA-3 couplers in the 1930s (they could be coupled with chain coupling), but all cars received automatic couplers in 1957.

Middle East

While the Middle East is mostly standard gauge, three different couplings appear to be in use (not counting Scharfenberg couplings on EMU trains). These are buffer-and-chain, American, and Russian types.

Africa

South of the Sahara, Janney (AAR) and chopper couplings (not necessarily of compatible types) appear to account for most couplings. The preferred and proposed UAR standard is the American Janney (AAR) coupling.

- Rail transport in Ghana

Brake couplings

Couplings are needed for any continuous braking systems.

Electronically controlled brakes

Electronically controlled pneumatic brakes (ECP) need a method of connecting electrically adjacent wagons, both for power and for command signals, and this can be done by plugs and sockets, or by very short range radio signals.

Model trains

On model railroads couplers vary according to scale, and have evolved over many years. Early model trains were coupled using various hook-and-loop arrangements, which were frequently asymmetrical, requiring all cars to be pointing in the same direction. In the larger scales, working scale or near-scale models of Janney couplers were quite common, but proved impractical in HO and smaller scales.

For many years, the "X2F" or "Horn-Hook" coupler was quite common in HO scale, as it could be produced as a single piece of moulded plastic. Similarly, for many years, a "lift-hook" coupler known as the *Rapido* and developed by Arnold, a German manufacturer of N-scale model trains, was commonly used in that scale.

The chief competitor of both these couplers, more popular among serious modellers, was the Magne-Matic, a magnetically-released knuckle coupler developed by Keith and Dale Edwards, and manufactured by Kadee, a company they started. While they closely resemble miniature Janney couplers, they are somewhat different mechanically, with the knuckle pivoting from the center of the coupler head, rather than from the side. A steel pin, designed to resemble an air brake hose, allows the couplers to be released magnetically; the design of the coupler head prevents this from happening unless the train is stopped or reversed with a mated pair of couplers directly over an uncoupling magnet. An earlier, mechanically-tripped version of the design had a straight pin extending down from the knuckle itself, which engaged a diamond-shaped mechanical "ramp" between the rails, which had to be raised above rail height when uncoupling was desired.

Once the Kadee patents ran out, a number of other manufacturers began to manufacture similar (and compatible) magnetic knuckle couplers.

Recently, an exact-scale HO model of the AAR coupler has been designed and manufactured by Frank Sergent, of Sergent Engineering. This design uses a tiny stainless steel ball to lock the knuckle closed. Uncoupling is achieved by holding a magnetic wand over the coupler pair to draw the balls out of the locking pockets.

In O scale, an exact-scale working miniature version of the "Alliance" coupler was manufactured from the 1980s by GAGO models in Australia. Since 2002 it has been marketed by the Waratah Model Railway Company European modellers tend to use scale hook and chain couplings.

In British 00 scale (similar to H0 scale) models the 'tension lock' coupler developed by Tri-ang is standard. This is similar in operation to the meatchopper type of coupling. Remote uncoupling is possible by using a sprung ramp between the rails. By halting the train over the ramp, it is split at this point. While it works well, it is often seen as ugly and obtrusive (although smaller designs are available, these are not always fully compatible with other models) and many British modellers prefer to retrofit either Kadee types or working hook and chain couplings.

A recent development is an interchangeable coupling which plugs into a standardised socket, known as NEM 362 and which can be easily unplugged as required. This allows the modeller to easily standardise on whatever coupling is desired, without individual manufacturers needing to change their coupling type.

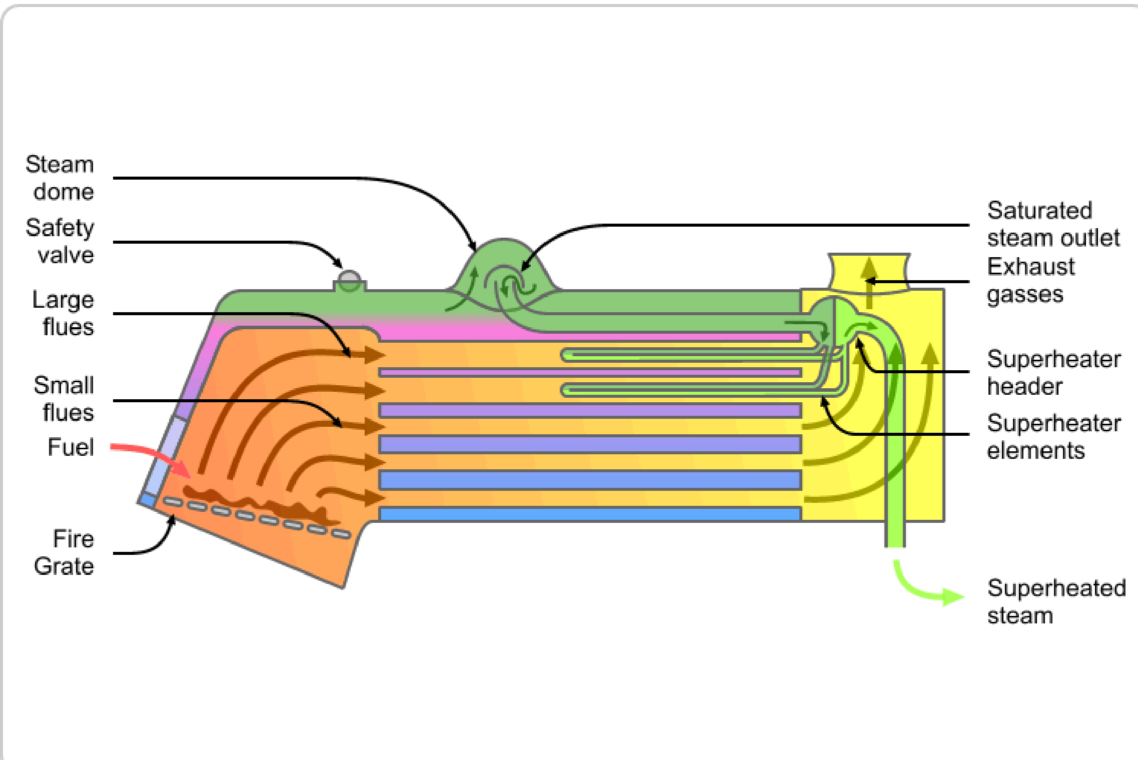
Accidents

Different kinds of coupling have different accident rates.

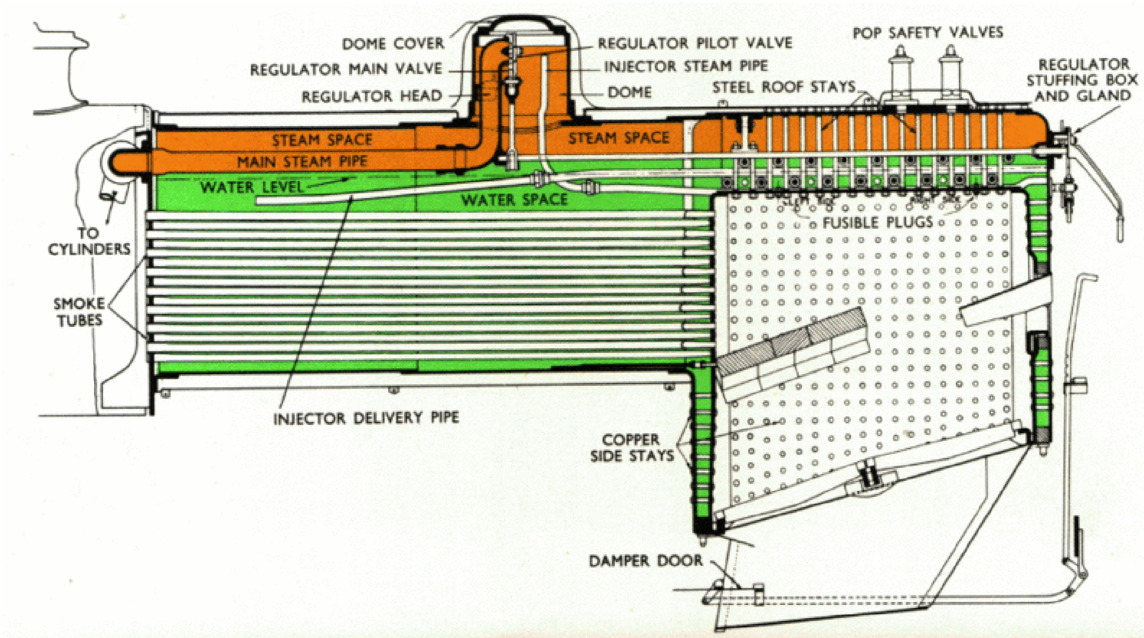
- UK 1906 - twelve fatal and 523 non-fatal accidents
- The Murulla rail accident of 1926 involved the breakage of a "drawhook" leading to a runaway and then a collision. Drawhooks imply "buffers and screw" couplings.

Chapter 7

Firebox (Steam Engine)



Components of a locomotive boiler, firebox at the left



Section of typical boiler and firebox

In a steam engine, the **firebox** is the area where the fuel is burned, producing heat to boil the water in the boiler. Most are somewhat box-shaped, hence the name.

Railway locomotive firebox

The firedoor into the firebox of a steam locomotive

In the standard steam locomotive firetube type boiler, the firebox is surrounded by water space on five sides. The underside is not so surrounded. If the engine burns solid fuel, there is a grate covering most of the bottom of the firebox to hold the fuel. An ashpan collects the solid combustion waste below. Combustion air generally enters at the base, and the airflow is usually controlled by damper doors.

Brick arch

There is a large brick arch (made from fire brick) at the front of the box which directs heat and flames back towards the firedoor at the rear. Without the arch, flames would be sucked straight into the firetubes, and only the front of the box would receive heat. The brick arch and the bars of the grate require periodic replacement due to the extreme heat they endure.

Firetubes

Firetubes are attached to one wall of the firebox (the front wall for a longitudinal boiler, the top for a vertical boiler) and carry the hot gaseous products of combustion through the boiler water, heating it, before they escape to the atmosphere.

Sheets and stays

Cutaway of locomotive firebox and boiler. Note the stays to support the "sheets" (plates) against pressure, the fusible plugs and the "mudhole" to allow access for scraping away scale

The metal walls of the firebox are normally called *sheets*, which are separated by *stays*. Since any corrosion is hidden, the stays may have longitudinal holes, called *tell-tales*, drilled in them which leak before they become unsafe. The *crown sheet* is the top of the firebox.

Belpaire firebox

Normally the top of the firebox is semicircular to match the contour of the boiler, however the Belpaire firebox has more of a square shape and is usually made as large as possible within the loading gauge, to offer the greatest heating surface where the fire is hottest.

Wootten firebox

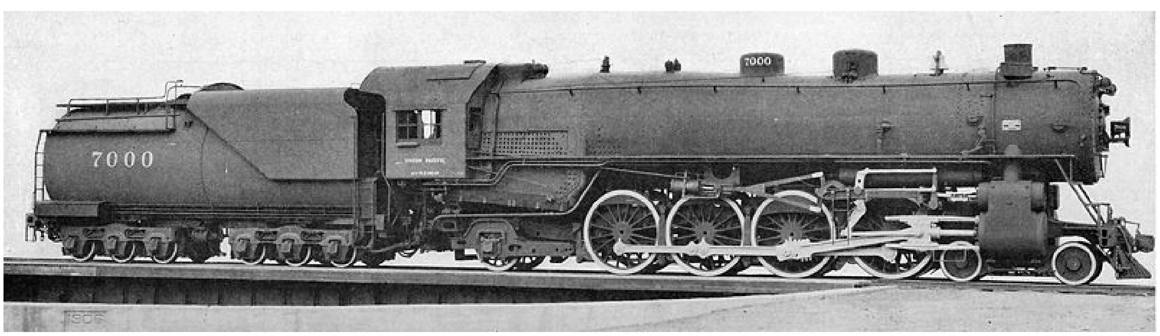
The Wootten firebox was very tall and wide to allow combustion of anthracite coal waste. Its size necessitated unusual placement of the crew, examples being camelback locomotives.

Combustion chamber

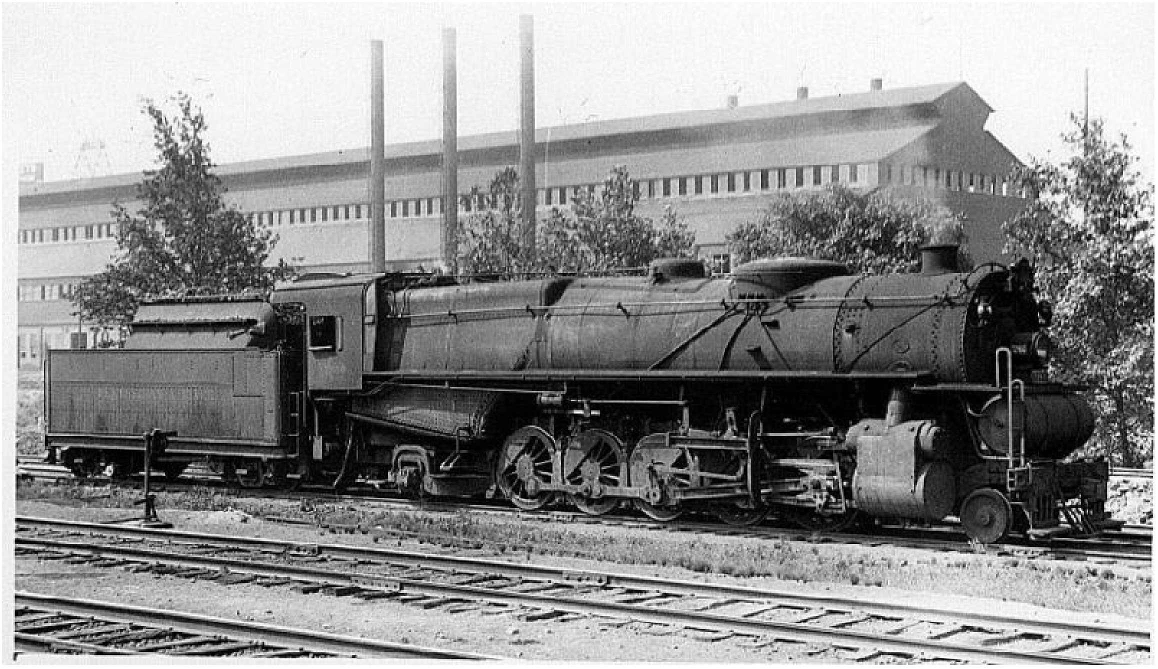
Some fireboxes were equipped with a so-called combustion chamber which placed additional space between the fire and the boiler. This allowed more complete combustion and thus greater heat.

Fireman's duties

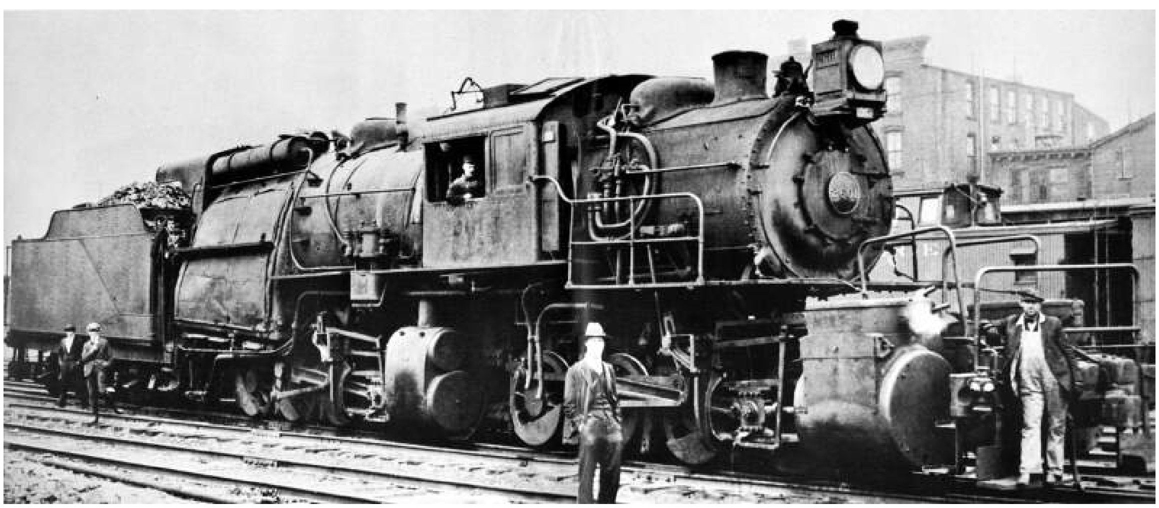
The fireman's role on a steam locomotive is to ensure the driver (engineer) has an adequate supply of steam at his disposal at all times. This is achieved by maintaining a supply of fuel to the fire, and by maintaining the boiler water level so that it covers the firebox crown sheet at all times – otherwise, the latter will overheat and weaken, and a boiler explosion may result. In addition, the fireman also serves as a backup for the driver, keeping a lookout ahead.



Locomotive with a normal firebox. The round top of the firebox makes attaching the boiler easier



The flat sides and square corners show the shape of the Belpaire firebox. This offers a greater heating surface, increasing the efficiency of the engine



The Wootten firebox can be seen as the large construction just in front of the tender. Note the unusual position of the drivers cab. The fireman was left exposed between firebox and tender

Road locomotive firebox

Road locomotives, such as traction engines, usually had fireboxes similar to those on railway locomotives but there were exceptions, e.g. the Sentinel steam waggon which had a vertical water tube boiler.

Stationary boiler firebox

There were, and are, many different designs of firebox for stationary boilers. In flue-type boilers (e.g. the Lancashire boiler) the flues themselves form the firebox. In water-tube boilers, the firebox is usually a firebrick-lined compartment below the water tubes.

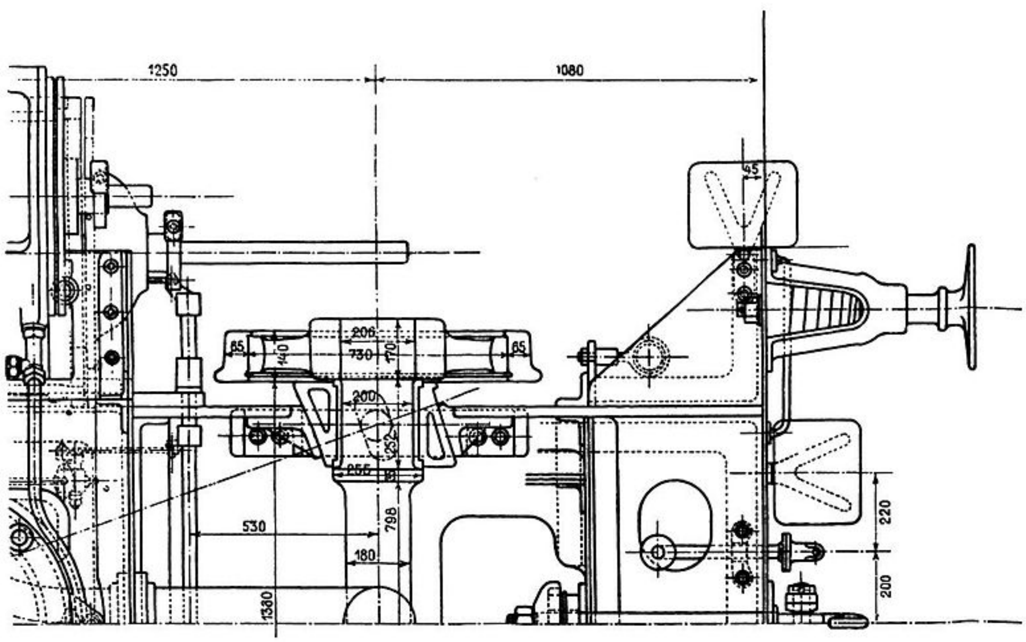
Marine boiler firebox

In marine boilers there are also various different types of firebox. The main distinction is, again, between fire-tube types (e.g. the Scotch boiler, with internal firebox) and water-tube types (e.g. the Yarrow boiler, with external firebox).

Chapter 8

Adams Axle and Blastpipe

Adams axle



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Construction drawing of a Adams axle

The **Adams axle** is a form of radial axle for rail locomotives that enable them to negotiate curves more easily. It was invented by William Bridges Adams and patented in 1865. The invention uses axle boxes that slide on an arc in shaped horn blocks, so allowing the axle to slide out to either side. This is similar to the movement of a Bissell truck, but with the notional centre point of the curve being where the pivot of the truck would be. This design, using slide bearings, is more expensive than one employing a shaft, but takes up less space.

Trials

In 1865 the Society of Engineers, London, made direct comparison between the radial axle, invented by William Bridges Adams, and a bogie design with an india-rubber central bearing invented by William Adams: during trials on the North London Railway the laterally sprung bogie was thought superior to the radial axle, but when William Adams moved from the NLR to the London and South Western Railway he adopted the design of his rival William Bridges Adams. The locomotives now known as Adams Radials are named after the LSWR Locomotive Superintendent, but are famous for the axle invented by William Bridges Adams.

Inventor

Notwithstanding the 1865 comparative trials of the two inventors' products, there is some confusion over the inventor of the axle. *Lexicon der Eisenbahn* cites William Adams (1823-1904) as the inventor indicates that William Bridges Adams (1797-1872) patented the invention.

Blastpipe

The **blastpipe** is part of the exhaust system of a steam locomotive that discharges exhaust steam from the cylinders into the smokebox beneath the chimney in order to increase the draught through the fire.

History

The primacy of discovery of the effect of directing the exhaust steam up the chimney as a means of providing draft through the fire is the matter of some controversy, Ahrons (1927) devoting significant attention to this matter. The exhaust from the cylinders on the first steam locomotive – built by Richard Trevithick – was directed up the chimney, and he noted its effect on increasing the draft through the fire at the time. At Wylam Timothy Hackworth also employed a blastpipe on his earliest locomotives, but it is not clear whether this was an independent discovery or a copy of Trevithick's design. Shortly after Hackworth George Stephenson also employed the same method, and again it is not clear whether that was an independent discovery or a copy of one of the other engineers.

The locomotives at the time employed either a single flue boiler or a single return flue, with the fire grate at one end of the flue. For boilers of this design the blast of a contracted orifice blastpipe was too strong, and would lift the fire. It was not until the development of the multitubular boiler that the centrally positioned, contracted orifice blastpipe became standard. The combination of multi-tube boiler and steam blast are often cited as the principal reasons for the high performance of *Rocket* of 1829 at the Rainhill Trials.

Description

Soon after the power of the steam blast was discovered it became apparent that a smokebox was needed beneath the chimney, to provide a space in which the exhaust gases emerging from the boiler tubes can mix with the steam. This had the added advantage of allowing access to collect the ash drawn through the fire tubes by the draught. The blastpipe, from which steam is emitted, was mounted directly beneath the chimney at the bottom of the smokebox.

The steam blast is largely self-regulating: an increase in the rate of steam consumption by the cylinders increases the blast, which increases the draught and hence the temperature of the fire. Modern locomotives are also fitted with a *blower*, which is a device that releases steam directly into the smokebox for use when a greater draught is needed without a greater volume of steam passing through the cylinders. An example of such situation is when the regulator is closed suddenly, or the train passes through a tunnel. If a single line tunnel is poorly ventilated, a locomotive entering at high speed can cause a rapid compression of the air within the tunnel. This compressed air may enter the chimney with substantial force. This can be extremely dangerous if the firebox door is open at the time. For this reason the blower is often turned on in these situations, to counteract the compression effect.

Later development

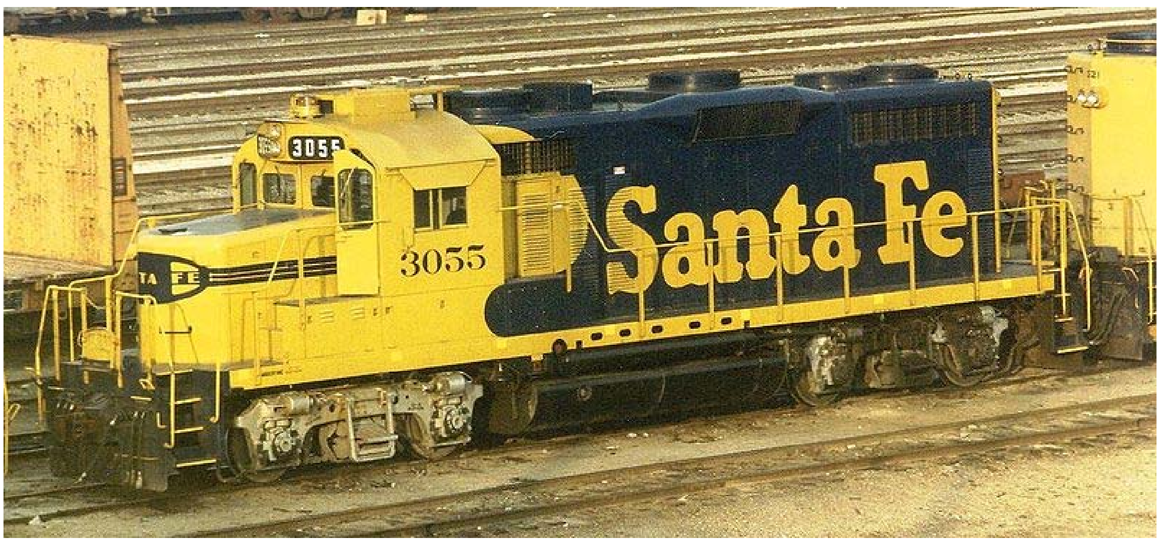
Little development of the basic principles of smokebox design took place until 1908, when the first comprehensive examination of steam-raising performance was carried out by W.F.M. Goss of Purdue University. These principles were adopted on the Great Western Railway by Churchward. A later development was the so-called *jumper-top* blastpipe which controlled the area of the blastpipe at different steaming rates to maximise efficiency.

The aim of blastpipe modification is to obtain maximum smokebox vacuum with minimum back pressure on the pistons. The simplest modification is a double chimney with twin blastpipes, but many other arrangements have been tried. Towards the end of the steam era the Kylchap exhaust was popular and used on the Nigel Gresley's Mallard. Other designs include Giesl, Lemaître and Lempor blastpipes.

Chapter 9

Blomberg B and Booster Engine

Blomberg B



ATSF #3055, an EMD GP20, rides on Blomberg B trucks.

Blomberg B detail

Blomberg M truck of a GP40-2

The **Blomberg B** was a "B" diesel locomotive truck. These trucks were the standard EMD four wheel truck from the FT up until the GP60. EMD introduced the truck in 1936. Unofficially it is named after Martin Blomberg, who joined the company the year before. The truck was derived from an earlier six wheel truck *(described in U.S. Patent 2,189,125, filed January 29, 1938, and approved February 6, 1940)*, and was used starting with the FT.

Identification

Blomberg trucks can be identified by their prominent outside swing hangers, which afford a better ride during side-to-side movement. The outside placement has the advantage of widening its spring base from 56 to 96 inches (1,422 to 2,438 mm).

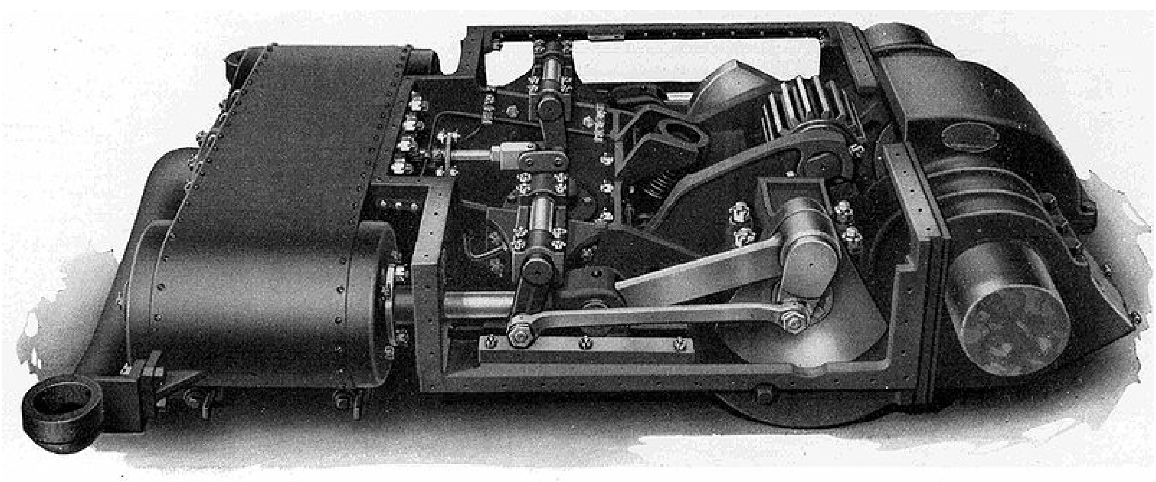
A popular modification by railroads in later years was reducing the number of brake shoes from 8 to 4 by reconfiguring the double-clasp brake rigging, removing one brake shoe per wheel. This can give the Blomberg B the appearance of later Blomberg M trucks.

M version

A modified (M) version of the truck called the **Blomberg M** was used starting with the four-axle Dash 2 series locomotives. Hydraulic snubbers (shocks) were used on diagonally opposite *(front right and rear left)* journals, and the leaf spring suspension was replaced with rubber pads. This version had only one brake actuating cylinder per side and revised brake rigging using threaded adjusters, reducing the number of brake shoes to 4 versus 8 on the earlier B model.

There is also a later variation of the Blomberg M found on the GP60 and F59PH models. The main spotting features of this version are leaf spring suspension (as opposed to rubber pads) and exposed roller bearing ends, along with damper shocks between the trucks and locomotive carbody to reduce sway. Similar looking trucks can be found under modern MPI MPXpress locomotives.

Booster engine



Booster engine with the cover removed to show the mechanism. The driven axle is on the right; the booster normally hung behind it.

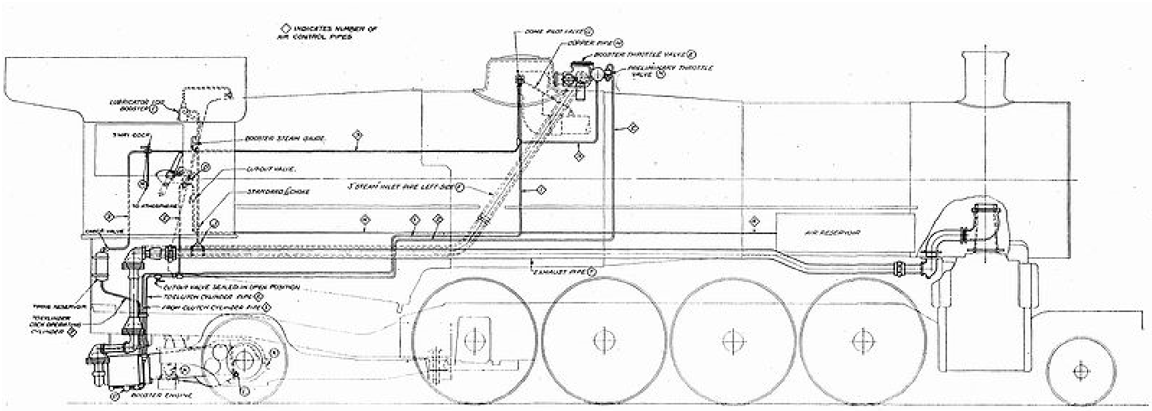


Diagram showing how a booster is installed and connected.

A **booster engine** for steam locomotives is a small two-cylinder steam engine back-gear-connected to the trailing truck axle on the locomotive or, if none, the lead truck on the tender. A rocking idler gear permits it to be put into operation by the engineer. It would drive one axle only and could be non-reversible with one idler gear or reversible with two idler gears.

They were used to start a heavy train or maintain low speed under demanding conditions. It could be cut in while moving at speeds under 15 mph (24 km/h). Rated at about 300 hp (224 kW) at speeds of from 10 to 30 miles per hour (16 to 48 km/h). It would automatically cut out at 30 mph (48 km/h). Tractive effort of 10-12,000 lbf (44 to 53 kN) was common.

Tender boosters were equipped with side-rods connecting axles on the lead truck. Such small side-rods restricted speed and thus confined to switching locomotives, often used in transfer service between yards. Such boosters were far rarer than engine boosters.

Reasons for booster use

The booster is intended to address fundamental flaws of the standard steam locomotive. First, most steam locomotives do not provide power to all wheels. The amount of force that can be applied to the rail depends on the weight on driven wheels and the factor of adhesion of the wheels against the track. Unpowered wheels effectively 'waste' weight which could be used for traction. Unpowered wheels are generally needed to provide stability at speed, but at low speed this is not necessary.

Second, the "gearing" of a steam locomotive is constant, since the pistons are linked directly to the wheels via rods and cranks. Since this is fixed, a compromise must be struck between ability to haul at low speed and the ability to run fast without inducing excessive piston speeds (which would cause failure) or the exhaustion of steam. This compromise means that the steam locomotive at low speeds is not able to use all the power the boiler is capable of producing; it simply cannot use steam that quickly, and there is a big gap between the amount of steam the boiler could produce and the amount that can be used. The booster enables that wasted potential to be put to use.

Disadvantages

Boosters were costly to maintain with their flexible steam and exhaust pipes, idler gear etc.

Usage

The booster saw most use in North America. Railway systems elsewhere often considered the expense and complexity unjustified.

Even in the North American region, booster engines were applied to only a fraction of all locomotives built. Some railroads used boosters extensively while others did not. The New York Central was a fan of the booster and applied it to all of its 4-6-4 Hudson locomotives. The rival Pennsylvania Railroad, however, used few booster-equipped locomotives.

Canadian Pacific Railway rostered a grand total of 3257 steam locomotives acquired between 1881 and 1949, yet only 55 were equipped with boosters. 17 H1 class 4-6-4s, 2 K1 class 4-8-4s and all 36 T1 class 2-10-4s.

In Australia, Victorian Railways equipped all but one of its X class 2-8-2 locomotives (built between 1929 and 1947) with a 'Franklin' two cylinder booster engine after the successful trial of the device on a smaller N class 2-8-2 in 1927. The South Australian Railways 500 class 4-8-2 heavy passenger locomotives were rebuilt into 4-8-4s with the addition of a booster truck from 1929 onwards.

NZR's Kb class of 1939 were built with booster trucks to enable the locomotives to handle the steeper grades of the South Island lines.

Chapter 10

Combustion Chamber and Connecting Rod

Combustion chamber

A **combustion chamber** is the part of an engine in which fuel is burned.

Internal combustion engine

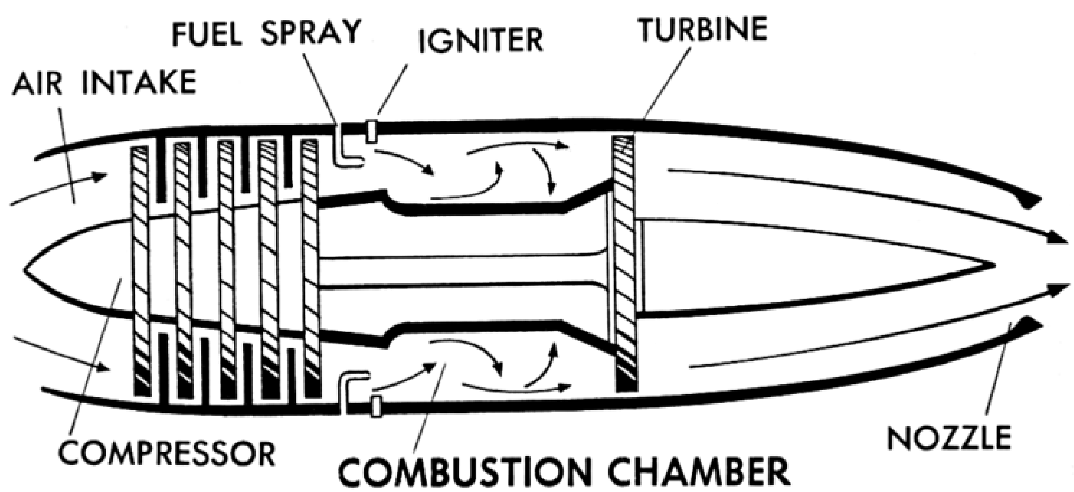


Diagram of jet engine showing the combustion chamber.

The hot gases produced by the combustion occupy a far greater volume than the original fuel, thus creating an increase in pressure within the limited volume of the chamber. This pressure can be used to do work, for example, to move a piston on a crankshaft or a turbine disc in a gas turbine. The energy can also be used to produce thrust when directed out of a nozzle as in a rocket engine.

Petrol or gasoline engine

A reciprocating engine is often designed so that the moving pistons are flush with the top of the cylinder block at top dead centre. The combustion chamber is recessed in the cylinder head and commonly contains a single intake valve and a single exhaust valve. Some engines use a dished piston and in this case the combustion chamber can be considered as partly within the cylinder. Various shapes of combustion chamber have been used, such as L-head (or flathead) for side-valve engines;"bathtub", "hemispherical" and "wedge" for overhead valve engines; and "pent-roof" for engines having 3, 4 or 5 valves per cylinder. The shape of the chamber has a marked effect on power output, efficiency and harmful emissions; the designer's objectives are to burn all of the mixture as completely as possible while avoiding excessive temperatures (which create NOx). This is best achieved with a compact rather than elongated chamber. The intake valve/port is usually placed to give the mixture a pronounced "swirl" (the term is preferred to turbulence which implies movement without overall pattern) above the rising piston, improving mixing and combustion. The shape of the piston top also affects the amount of swirl. Note that swirl rotates about a horizontal axis, not (symmetrically) about a vertical axis. Finally, the spark plug must be situated in a position from which the flame front can reach all parts of the chamber at the desired point, usually around 15 degrees after top dead centre. It is strongly desirable to avoid narrow crevices where stagnant "end gas" can become trapped, as this tends to detonate violently after the main charge, adding little useful work and potentially damaging the engine. Also, the residual gases displace room for fresh air/fuel mixture and will thus reduce the power potential of each firing stroke.

Diesel engine

Diesel engines fall into two broad classes:

- Direct injection, where the combustion chamber consists of a dished piston
- Indirect injection, where the combustion chamber is in the cylinder head

Direct injection engines usually give better fuel economy but indirect injection engines can use a lower grade of fuel.

Harry Ricardo was prominent in developing combustion chambers for diesel engines, the best known being the Ricardo Comet.

Gas turbine

The combustion chamber in gas turbines and jet engines (including ramjets and scramjets) is called the combustor.

The combustor is fed high pressure air by the compression system, adds fuel and burns the mix and feeds the hot, high pressure exhaust into the turbine components of the engine or out the exhaust nozzle.

Different types of combustors exist, mainly:

- Can type: Can combustors are self contained cylindrical combustion chambers. Each "can" has its own fuel injector, igniter, liner, and casing.
- Cannular type: Like the can type combustor, can annular combustors have discrete combustion zones contained in separate liners with their own fuel injectors. Unlike the can combustor, all the combustion zones share a common ring (annulus) casing.
- Annular type: Annular combustors do away with the separate combustion zones and simply have a continuous liner and casing in a ring (the annulus).

Steam engine

The term **combustion chamber** is also used to refer to an additional space between the firebox and boiler in a steam locomotive. This space is used to allow further combustion of the fuel, providing greater heat to the boiler.

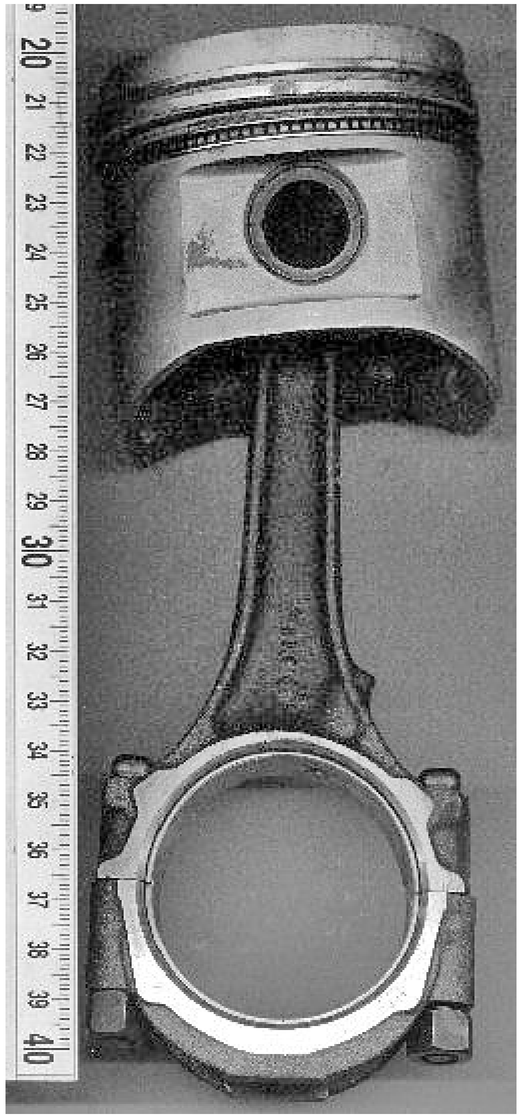
Large steam locomotives usually have a combustion chamber in the boiler to allow the use of shorter firetubes. This is because:

- Long firetubes have a theoretical advantage in providing a large heating surface but, beyond a certain length, this is subject to diminishing returns.
- Very long firetubes are prone to sagging in the middle.

Micro Combustion Chambers

Micro combustion chambers are the devices in which combustion happens at a very small volume, due to which surface to volume ratio increases which plays a vital role in stabilizing the flame.

Connecting rod



piston (top) and connecting rod from typical automotive engine (scale is in centimetres)

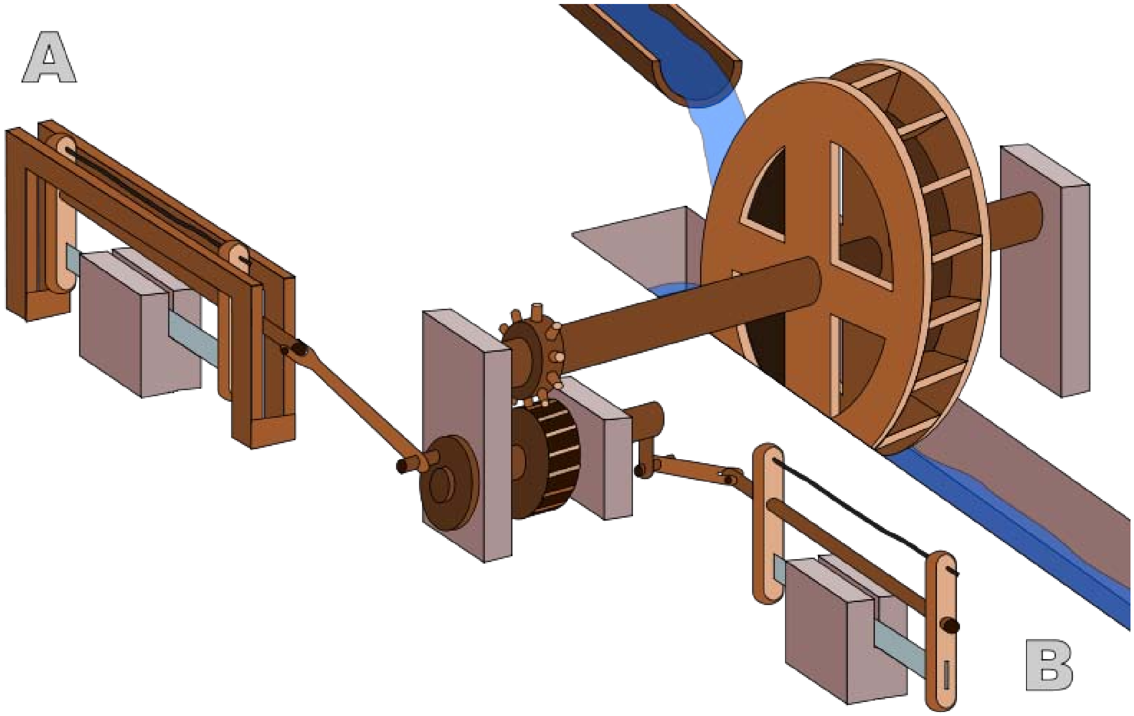
In a reciprocating piston engine, the **connecting rod** or **conrod** connects the piston to the crank or crankshaft. Together with the crank, they form a simple mechanism that converts linear motion into rotating motion.

Connecting rods may also convert rotating motion into linear motion. Historically, before the development of engines, they were first used in this way.

As a connecting rod is rigid, it may transmit either a push or a pull and so the rod may rotate the crank through both halves of a revolution, i.e. piston pushing and piston pulling. Earlier mechanisms, such as chains, could only pull. In a few two-stroke engines, the connecting rod is only required to push.

Today, connecting rods are best known through their use in internal combustion piston engines, such as car engines. These are of a distinctly different design from earlier forms of connecting rods, used in steam engines and steam locomotives.

History



Scheme of the Roman Hierapolis sawmill, the earliest known machine to combine a connecting rod with a crank.

The earliest evidence for a connecting rod appears in the late 3rd century AD Roman Hierapolis sawmill. It also appears in two 6th century Eastern Roman saw mills excavated at Ephesus respectively Gerasa. The crank and connecting rod mechanism of these Roman watermills converted the rotary motion of the waterwheel into the linear movement of the saw blades.

Sometime between 1174 and 1206, the Arab inventor and engineer Al-Jazari described a machine which incorporated the connecting rod with a crankshaft to pump water as part of a water-raising machine, but the device was unnecessarily complex indicating that he still did not fully understand the concept of power conversion.

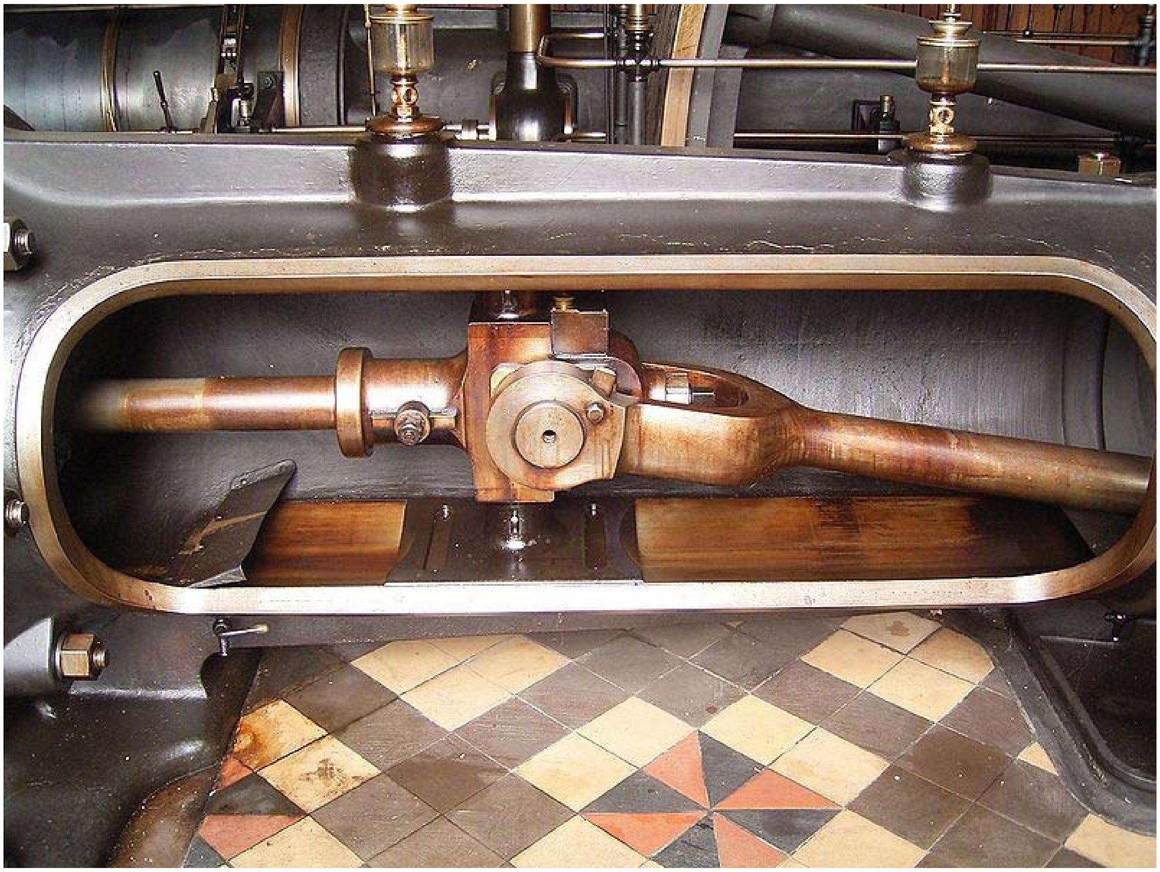
In Renaissance Italy, the earliest evidence of a − albeit mechanically misunderstood − compound crank and connecting-rod is found in the sketch books of Taccola. A sound understanding of the motion involved displays the painter Pisanello (d. 1455) who showed a piston-pump driven by a water-wheel and operated by two simple cranks and two connecting-rods.

By the 16th century, evidence of cranks and connecting rods in the technological treatises and artwork of Renaissance Europe becomes abundant; Agostino Ramelli's *The Diverse and Artifactitious Machines* of 1588 alone depicts eighteen examples, a number which rises in the *Theatrum Machinarum Novum* by Georg Andreas Böckler to 45 different machines.

Steam engines

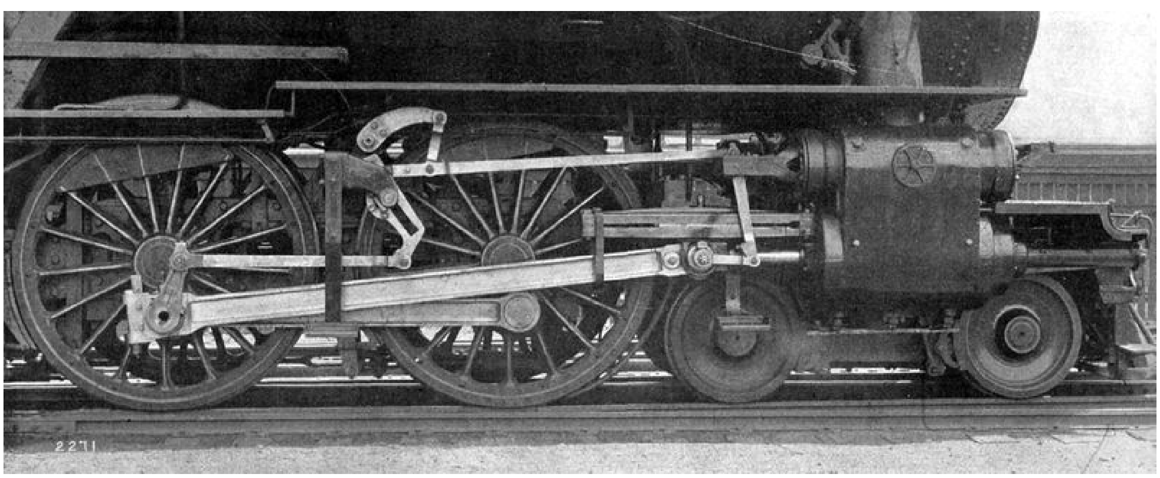
Beam engine, with twin connecting rods (almost vertical) between the horizontal beam and the flywheel cranks

The first steam engines, Newcomen's atmospheric engine, was single-acting: its piston only did work in one direction, and so these used a chain rather than a connecting rod. Their output rocked back and forth, rather than rotating continuously.



Crosshead of a stationary steam engine: piston rod to the left, connecting rod to the right

Steam engines after this are usually double-acting: their internal pressure works on each side of the piston in turn. This requires a seal around the piston rod and so the hinge between the piston and connecting rod is placed outside the cylinder, in a large sliding bearing block called a crosshead.



Steam locomotive rods, the large angled rod being the connecting rod

In a steam locomotive, the crank pins are usually mounted directly on one or more pairs of driving wheels, and the axle of these wheels serves as the crankshaft. The connecting rods, also called the **main rods** (*in US practice*), run between the crank pins and crossheads, where they connect to the piston rods. Crossheads or trunk guides are also used on large diesel engines manufactured for marine service. The similar rods between driving wheels are called **coupling rods** (*in British practice*).

The connecting rods of smaller steam locomotives are usually of rectangular cross-section but, on small locomotives, marine-type rods of circular cross-section have occasionally been used. Stephen Lewin, who built both locomotive and marine engines, was a frequent user of round rods. Gresley's A4 Pacifics, such as *Mallard, had an alloy steel connecting rod with a web that was only 3/8" thick.*

On Western Rivers steamboats, the connecting rods are properly called **pitmans**, and are sometimes incorrectly referred to as pitman arms.

Internal combustion engines

Failure of a connecting rod is one of the most common causes of catastrophic engine failure.

In modern automotive internal combustion engines, the connecting rods are most usually made of steel for production engines, but can be made of T6-2024 and T651-7075 aluminum alloys (for lightness and the ability to absorb high impact at the expense of durability) or titanium (for a combination of lightness with strength, at higher cost) for high performance engines, or of cast iron for applications such as motor scooters. They are not rigidly fixed at either end, so that the angle between the connecting rod and the piston can change as the rod moves up and down and rotates around the crankshaft. Connecting rods, especially in racing engines, may be called "billet" rods, if they are machined out of a solid billet of metal, rather than being cast.

The **small end** attaches to the piston pin, gudgeon pin or wrist pin, which is currently most often press fit into the connecting rod but can swivel in the piston, a "floating wrist pin" design. The **big end** connects to the bearing journal on the crank throw, in most engines running on replaceable bearing shells accessible via the *connecting rod bolts* which hold the bearing "cap" onto the big end. Typically there is a pinhole bored through the bearing and the big end of the connecting rod so that pressurized lubricating motor oil squirts out onto the thrust side of the cylinder wall to lubricate the travel of the pistons and piston rings. Most small two-stroke engines and some single cylinder four-stroke engines avoid the need for a pumped lubrication system by using a rolling-element bearing instead, however this requires the crankshaft to be pressed apart and then back together in order to replace a connecting rod.

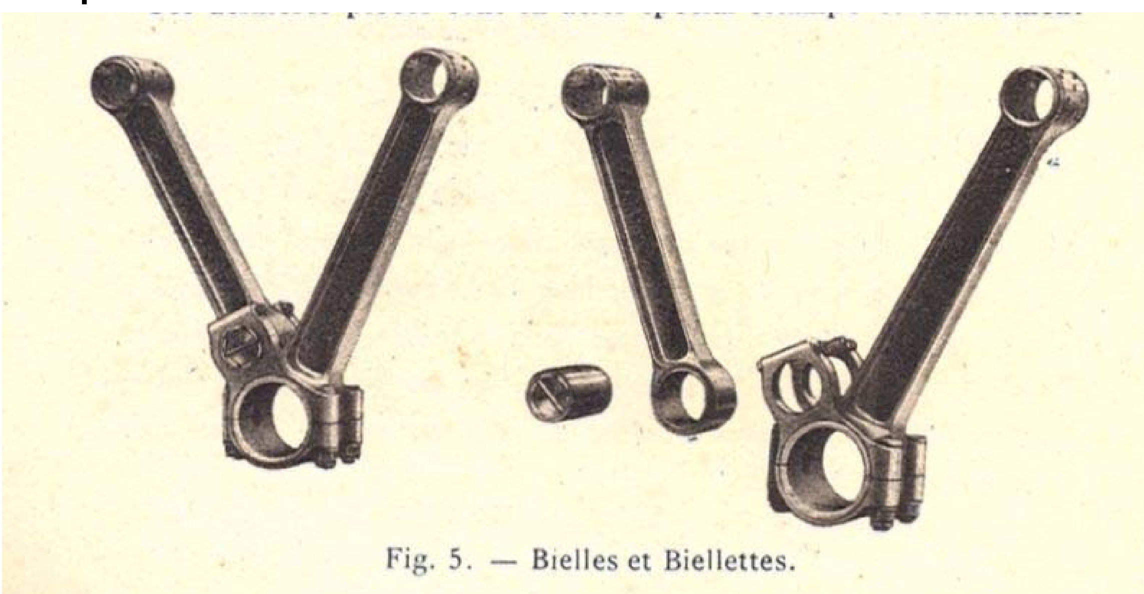
The connecting rod is under tremendous stress from the reciprocating load represented by the piston, actually stretching and being compressed with every rotation, and the load increases to the square of the engine speed increase. Failure of a connecting rod, usually called "throwing a rod" is one of the most common causes of catastrophic engine failure in cars, frequently putting the broken rod through the side of the crankcase and thereby rendering the engine irreparable; it can result from fatigue near a physical defect in the rod, lubrication failure in a bearing due to faulty maintenance, or from failure of the rod bolts from a defect, improper tightening. Re-use of rod bolts is a common practice as long as the bolts meet manufacturer specifications. Despite their frequent occurrence on televised competitive automobile events, such failures are quite rare on production cars during normal daily driving. This is because production auto parts have a much larger factor of safety, and often more systematic quality control.

When building a high performance engine, great attention is paid to the connecting rods, eliminating stress risers by such techniques as grinding the edges of the rod to a smooth radius, shot peening to induce compressive surface stresses (to prevent crack initiation), balancing all connecting rod/piston assemblies to the same weight and Magnafluxing to reveal otherwise invisible small cracks which would cause the rod to fail under stress. In addition, great care is taken to torque the connecting rod bolts to the exact value specified; often these bolts must be replaced rather than reused. The big end of the rod is fabricated as a unit and cut or cracked in two to establish precision fit around the big end bearing shell. Therefore, the big end "caps" are not interchangeable between connecting rods, and when rebuilding an engine, care must be taken to ensure that the caps of the different connecting rods are not mixed up. Both the connecting rod and its bearing cap are usually embossed with the corresponding position number in the engine block.

Recent engines such as the Ford 4.6 liter engine and the Chrysler 2.0 liter engine, have connecting rods made using powder metallurgy, which allows more precise control of size and weight with less machining and less excess mass to be machined off for balancing. The cap is then separated from the rod by a fracturing process, which results in an uneven mating surface due to the grain of the powdered metal. This ensures that upon reassembly, the cap will be perfectly positioned with respect to the rod, compared to the minor misalignments which can occur if the mating surfaces are both flat.

A major source of engine wear is the sideways force exerted on the piston through the connecting rod by the crankshaft, which typically wears the cylinder into an oval cross-section rather than circular, making it impossible for piston rings to correctly seal against the cylinder walls. Geometrically, it can be seen that longer connecting rods will reduce the amount of this sideways force, and therefore lead to longer engine life. However, for a given engine block, the sum of the length of the connecting rod plus the piston stroke is a fixed number, determined by the fixed distance between the crankshaft axis and the top of the cylinder block where the cylinder head fastens; thus, for a given cylinder block longer stroke, giving greater engine displacement and power, requires a shorter connecting rod (or a piston with smaller compression height), resulting in accelerated cylinder wear.

Compound rods



Articulated connecting rods

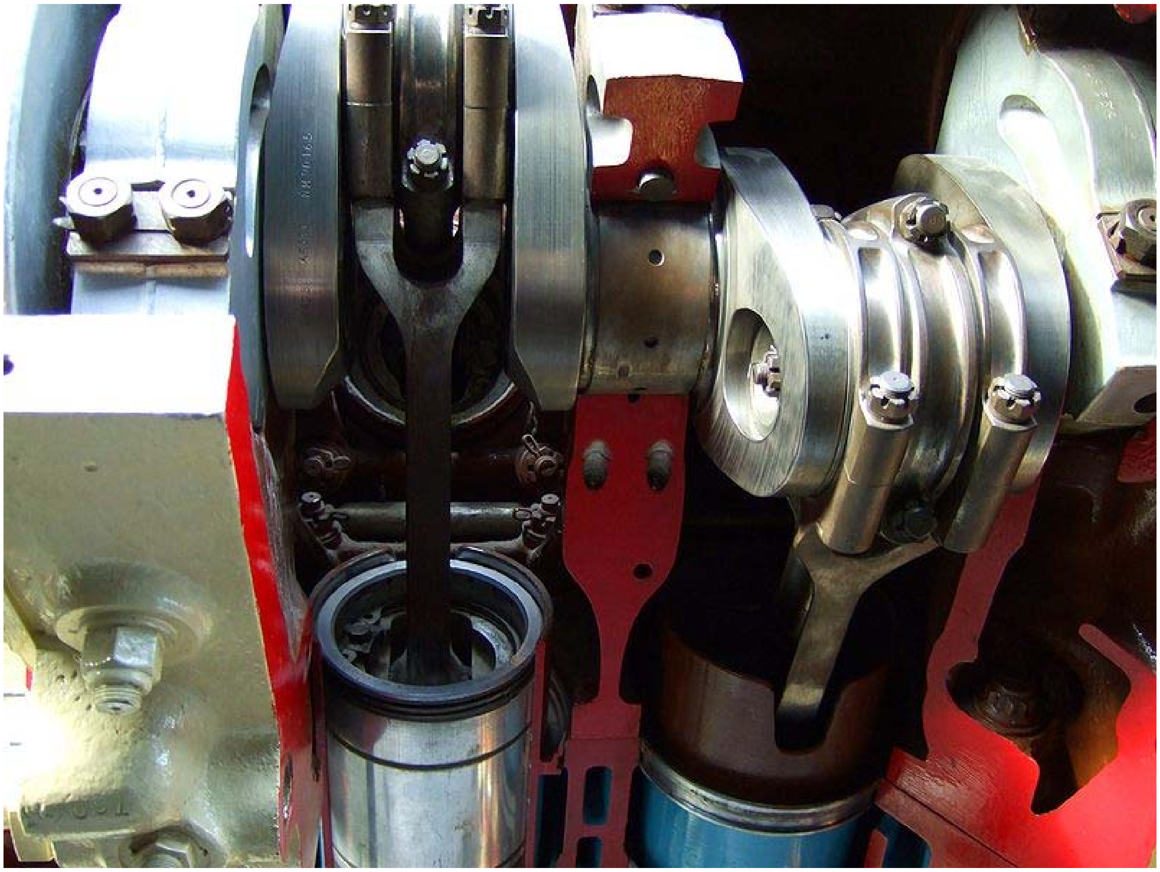
Many-cylinder multi-bank engines such as a V12 layout have little space available for many connecting rod journals on a limited length of crankshaft. This is a difficult compromise to solve and its consequence has often led to engines being regarded as failures (Sunbeam Arab, Rolls-Royce Vulture).

The simplest solution, almost universal in road car engines, is to use simple rods where cylinders from both banks share a journal. This requires the rod bearings to be *narrower*, increasing bearing load and the risk of failure in a high-performance engine. This also means the opposing cylinders are not exactly in line with each other.

In certain engine types, master/slave rods are used rather than the simple type shown in the picture above. The master rod carries one or more ring pins to which are bolted the much smaller big ends of slave rods on other cylinders. Certain designs of V engines use a master/slave rod for each pair of opposite cylinders. A drawback of this is that the stroke of the subsidiary rod is slightly shorter than the master, which increases vibration in a vee engine, catastrophically so for the Sunbeam Arab.

BMW 132 radial aero engine rods

Radial engines typically have a master rod for one cylinder and multiple slave rods for all the other cylinders in the same bank.



Fork and blade rods of a Napier Deltic

The usual solution for high-performance aero-engines is a "forked" connecting rod. One rod is split in two at the big end and the other is thinned to fit into this fork. The journal is still shared between cylinders. The Rolls-Royce Merlin used this "fork-and-blade" style.

Chapter 11

Countersteam Brake and Coupling Rod

Countersteam brake

A **countersteam brake** is a brake on a steam locomotive that uses the engine (specifically the cylinders) to help brake the locomotive.

It uses the working principle of steam cylinders fitted with piston valves such that, by changing the configuration of the valve gear, the motion of the valves is also altered such that they work in opposition to the movement of the pistons.

Because of the inertia of a steam locomotive in its initial direction of travel, changing the direction in which the steam cylinders have to work acts first to brake the movement of the connecting rod, which in turn slows the transmission of power to the drive of the locomotive until it stops.

The countersteam brake is often confused with the counterpressure brake, which works with air, not steam, and acts as a dynamic brake. Unlike the countersteam brake, the counterpressure brake is permitted to be used as an independent braking system in its own right.

Operation

The countersteam brake is actually not a brake in the true sense; but simply a way of using the working principle of a steam engine to produce a braking effect. It is therefore not a separate component of a steam locomotive. Countersteam braking is however only achievable with piston valves. On simple slide valves, no opposing steam admission is possible due to the way they are constructed.

Using the countersteam brake, experienced locomotive drivers can reverse the running direction of a steam locomotive almost as if it hasn't been brought to a stop, because the actual changeover point occurs whilst the locomotive is still moving in the initial direction of travel. This technique requires detailed knowledge and experience because if it is not carried out correctly, damage to the locomotive engine may result.

On steam locomotives without a second independent brake system (like e.g. a compressed-air brake, vacuum brake or steam brake) for the engine, in addition to the usual counterweight or fixed brake, the countersteam brake was used as a braking system. Today, steam locomotives generally have to have two independent brake systems in order to be licensed, so that the countersteam brake is not viewed as a braking system, but is nevertheless still used.

Coupling rod

connecting rod and coupling rods attached to a small locomotive driving wheel

A **coupling rod** or **side rod** connects the driving wheels of a locomotive. Steam locomotives in particular usually have them, but some diesel and electric locomotives, especially older ones and shunters, also have them. The coupling rods transfer the power to all the wheels.

Development

Locomotion No 1 was the first locomotive to employ coupling rods rather than chains. In the 1930s reliable roller bearing coupling rods were developed.

Balancing

The coupling rod's off-center attachment to the outside of the driving wheel inevitably creates an eccentric movement and vibration when in motion. To compensate for this, the driving wheels always had built-in counterweights that somewhat offset the angular momentum of the coupling rods. This vibration reduction was more effective when the rods move horizontally and less so when they are moving vertically. A counterweight is clearly visible at the top of the wheel in the image.

Coupling rods move in vertical motion as well as horizontally as the wheels rotate, but the engine's piston and its immediate attachments only move horizontally. Because the momentum of the connecting rods alone in up and down motion is considerably less than that resulting from the combined horizontal movement of the connecting rods, piston and driving rod, a wheel counterweight cannot be made to balance the entire assembly perfectly during its complete rotation. The counterweights have to be fixed in one position on their driving wheel to avoid a design complexity that would be both unreliable and unmaintainable.

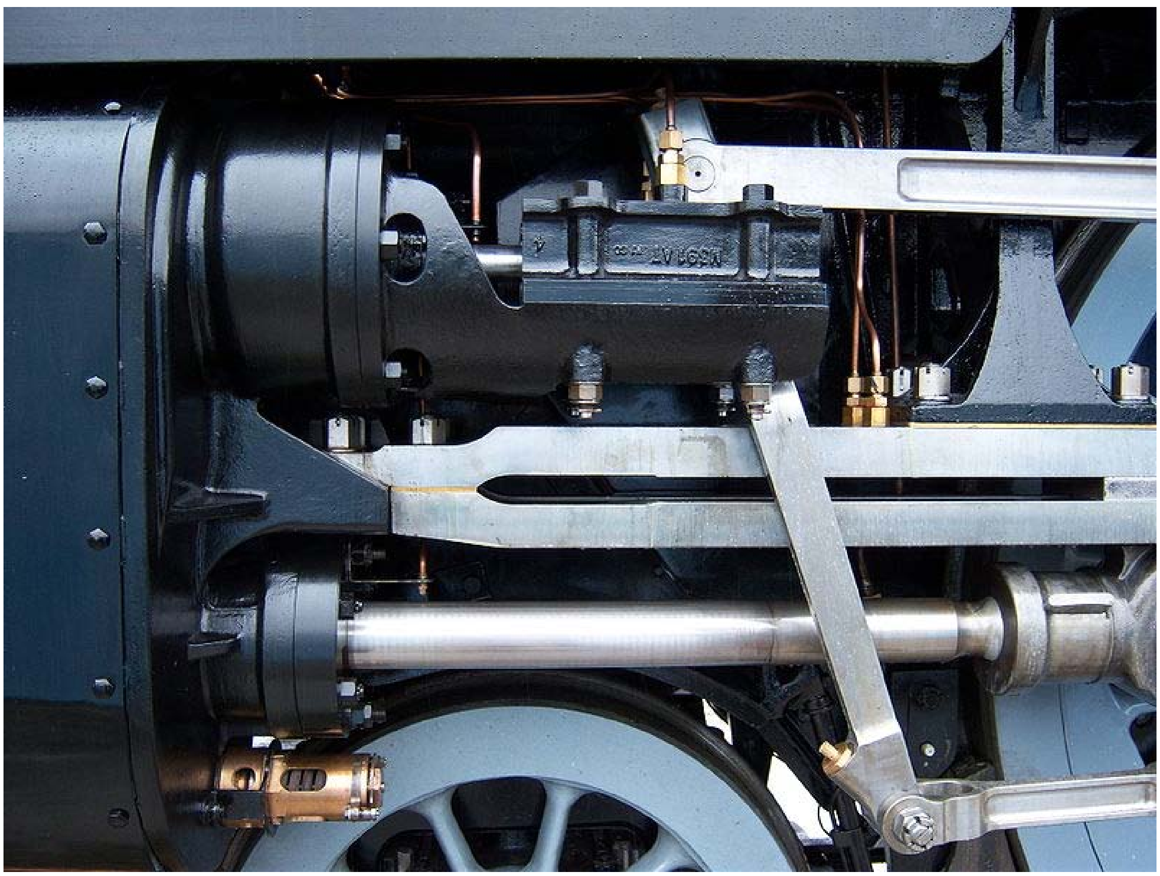
An inevitable vibration that results during the complete circular movement of the driving wheels and rods is called hammering and it is destructive to both the locomotive and the roadbed. In some locomotives, this hammering is so intense that at speed, the drivers alternately jump from the rail head, then slam down hard on the rails as the wheels complete their rotation. Unfortunately, hammering is inherent to conventional two-cylinder piston-driven steam locomotives and that is one of the several reasons they have been retired from service.

Materials

Initially, coupling rods were made of steel. As technology progressed and better materials became available, the connecting rods were manufactured of lighter and stronger alloys, which in turn permitted smaller counterweights and also reduced hammering.

Chapter 12

Cylinder (Locomotive)



The 'motion' on the left-hand side of 60163 *Tornado*. The black casting to the left houses the cylinder, in which slides the piston; the piston rod is immediately above the wheel.

The **cylinders** of a **steam locomotive** are the components that convert the power stored in the steam into motion.

Cylinders may be arranged in several different ways.

Early locomotives

On early locomotives (e.g. Puffing Billy) the cylinders were often set vertical and the motion was transmitted through beams, as in a beam engine.

Direct drive

The next stage (e.g. Stephenson's Rocket) was to drive the wheels directly from steeply inclined cylinders placed at the back of the locomotive. Direct drive became the standard arrangement but the cylinders were moved to the front and placed either horizontal or nearly horizontal.

Inside or outside cylinders

The front-mounted cylinders could be placed either inside (between the frames) or outside. Examples:

- Inside cylinders, Planet locomotive
- Outside cylinders, GNR Stirling 4-2-2

In the 19th and early 20th centuries, inside cylinders were widely used in the UK but outside cylinders were more common in Continental Europe and the USA. The reason for this difference is unclear. From about 1920, outside cylinders became more common in the UK but many inside-cylinder engines continued to be built.

Three or four cylinders

The demand for more power led to the development of engines with three cylinders (two outside and one inside) or four cylinders (two outside and two inside). Examples:

- Three cylinders, SR Class V
- Four Cylinders, LMS Princess Royal Class

Crank angles

On a two-cylinder engine the cranks, whether inside or outside, are set at 90 degrees. As the cylinders are double-acting (i.e. fed with steam alternately at each end) this gives four impulses per revolution and ensures that there are no dead centres.

On a three-cylinder engine, two arrangements are possible:

- cranks set to give six equally-spaced impulses per revolution – the usual arrangement. If the three cylinder axes are parallel the cranks will be 120 degrees apart, but if the centre cylinder does not drive the leading driving axle it will probably be inclined (as on most US three-cylinder locomotives and on some of

Gresley's three-cylinder locomotives in Great Britain) and the inside crank will be correspondingly shifted from 120 degrees.
- outside cranks set at 90 degrees, inside crank set at 135 degrees, giving six unequally spaced impulses per revolution. This arrangement was sometimes used on three-cylinder compound locomotives which used the outside (low pressure) cylinders for starting. This will give evenly-spaced exhausts when the engine is working compound.

Two arrangements are also possible on a four-cylinder engine:

- all four cranks set at 90 degrees. With this arrangement the cylinders act in pairs so there are four impulses per revolution, as with a two-cylinder engine.
- pairs of cranks set at 90 degrees with the inside pair set at 45 degrees to the outside pair. This gives eight impulses per revolution. It increases weight and complexity, by requiring four sets of valve gear, but gives smoother torque and reduces the risk of slipping.

Valves

The **valve chests** or **steam chests** which contain the slide valves or piston valves may be located in various positions.

Inside cylinders

If the cylinders are small, the valve chests may be located between the cylinders. For larger cylinders the valve chests are usually on top of the cylinders but, in early locomotives, they were sometimes underneath the cylinders.

Outside cylinders

The valve chests are usually on top of the cylinders but, in older locomotives, the valve chests were sometimes located alongside the cylinders and inserted through slots in the frames. This meant that, while the cylinders were outside, the valves were inside and could be driven by inside valve gear.

Valve gear

There are many variations in the location of the valve gear. In British practice, inside valve gear is usually of the Stephenson type while outside valve gear is usually of the Walschaerts type. However, this is not a rigid rule and most types of valve gear are capable of being used either inside or outside. Joy valve gear was once popular, e.g. on the LNWR G Class.

Inside cylinders

On inside cylinder engines the valve gear is nearly always inside (between the frames), e.g. LMS Fowler Class 3F.

Outside cylinders

On engines with outside cylinders there are three possible variations:

- Inside valve gear driving inside valves, e.g. NER Class T2
- Inside valve gear driving outside valves through rocking shafts, e.g. GWR 4900 Class
- Outside valve gear driving outside valves, e.g. LSWR N15 Class

Three cylinders

There are three common variations:

- Three sets of valve gear (two outside, one inside), e.g. LNER Peppercorn Class A2
- Outside valve gear driving the outside valves. Inside valve driven by Gresley conjugated valve gear, e.g. LNER Class A1/A3
- Three sets of inside valve gear (all valves inside), e.g. NER Class T3

Four cylinders

There are three common variations:

- Four sets of valve gear (two outside, two inside), e.g. SR Lord Nelson Class
- Inside valve gear driving the inside valves directly and the outside valves via rocking shafts, e.g. GWR 4073 Class
- Outside valve gear driving the outside valves directly and the inside valves via rocking shafts, e.g. LMS Princess Coronation Class

Other variations

The cylinders on a Shay locomotive.

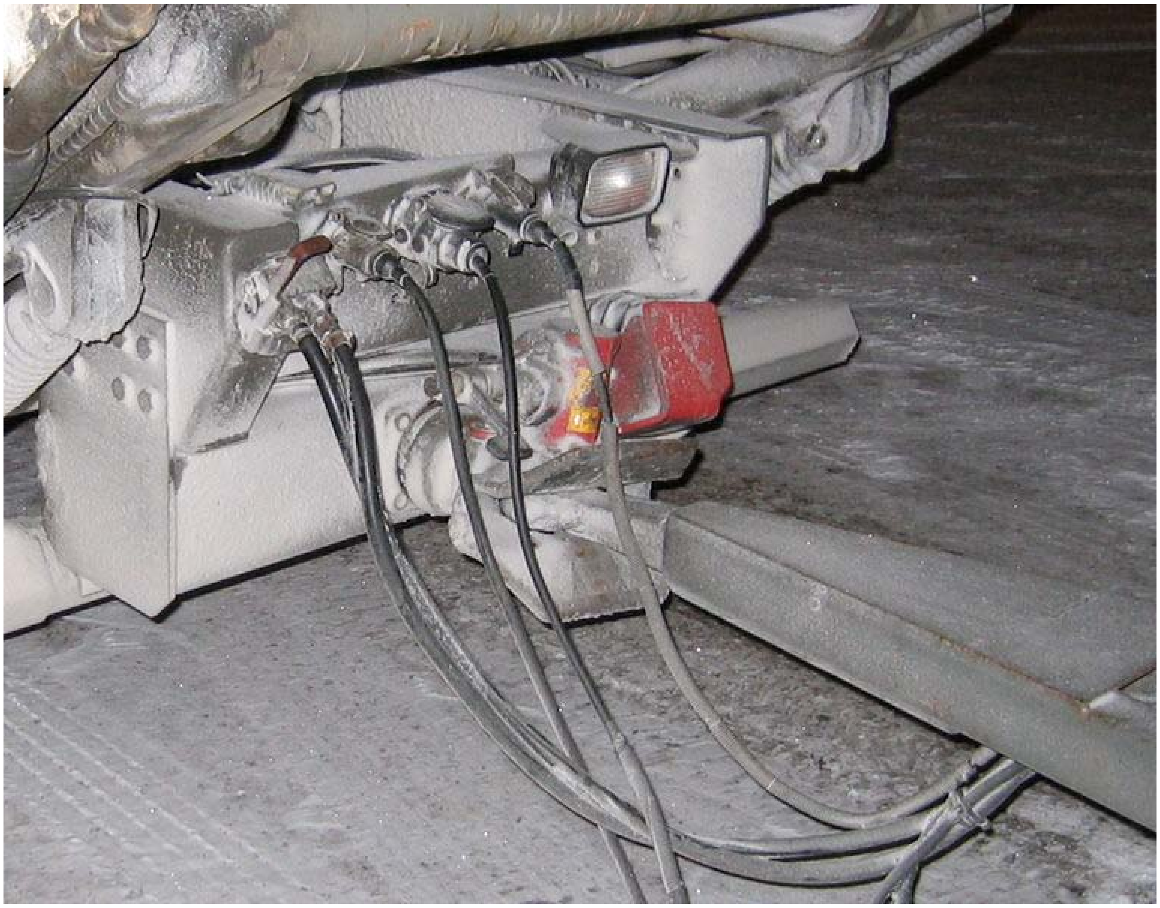
There are many other variations, e.g. geared steam locomotives which may have only one cylinder. The only conventional steam locomotive with one cylinder that is known is the Nielson One-Cylinder Locomotive.

Chapter 13

Drawbar (Haulage) and Driving Wheel

Drawbar (haulage)

Pickfords ballast tractor with exceptional load on specialist trailer. The tractor is a Scammell, and is connected to the trailer via a drawbar.



Heavy duty drawbar system on a truck

A **drawbar** is a solid coupling between a hauling vehicle and its hauled load. Drawbars are in common use with rail transport, road trailers, both large and small, industrial and recreational, and with agricultural equipment.

Agriculture

Agricultural equipment is hauled from a tractor mounted drawbar. Specialist agricultural tools such as ploughs are attached to specialist drawbars which have functions in addition to transmitting tractive force.

Road

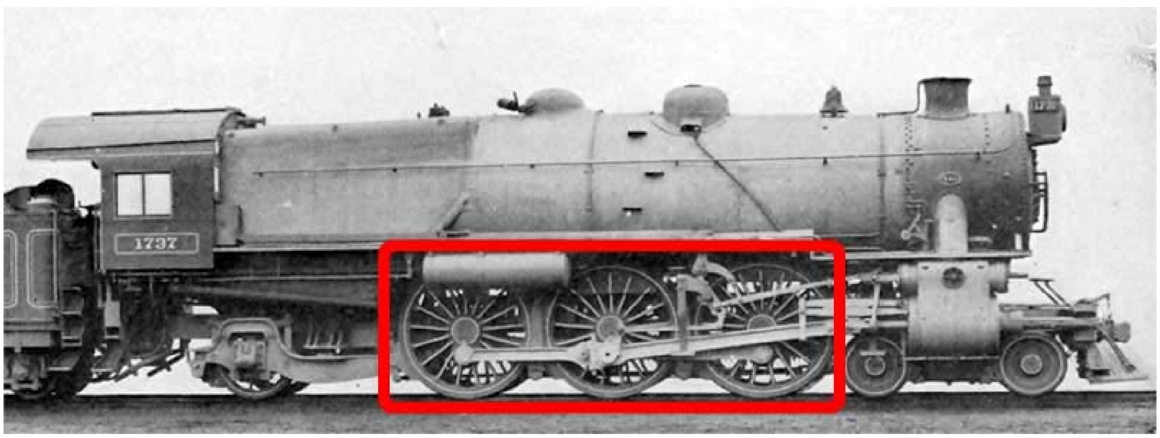
The drawbar should not be confused with the fifth wheel coupling. The drawbar requires a trailer which either loads the drawbar lightly (for example a small boat trailer, or caravan, where a load of up to ~50 kg is part of correct trailer loading practice), or the load is the weight of the coupling components only (larger trailers, usually but not always with a steerable hauled axle, front or rear). By contrast, the fifth wheel is designed to transmit a major proportion of the load's weight to the hauling vehicle.

A drawbar is mounted or located on the tractive vehicle and is used to accept the coupling of the load. The direction of haulage may be push or pull, though pushing tends to be for a pair of ballast tractors working one pulling and the other pushing an exceptional load on a specialist trailer.

Rail

A rail locomotive hauls its load through a drawbar and hauling force is transmitted between rolling stock via drawbars between units. With rail transport the tractive effort is "cascaded" through the train of wagons. Each wagon, even though unpowered, may be considered the tractive vehicle for the wagon(s) further away in the chain.

Driving wheel



The driving wheels (boxed) on a 4-6-2 locomotive.

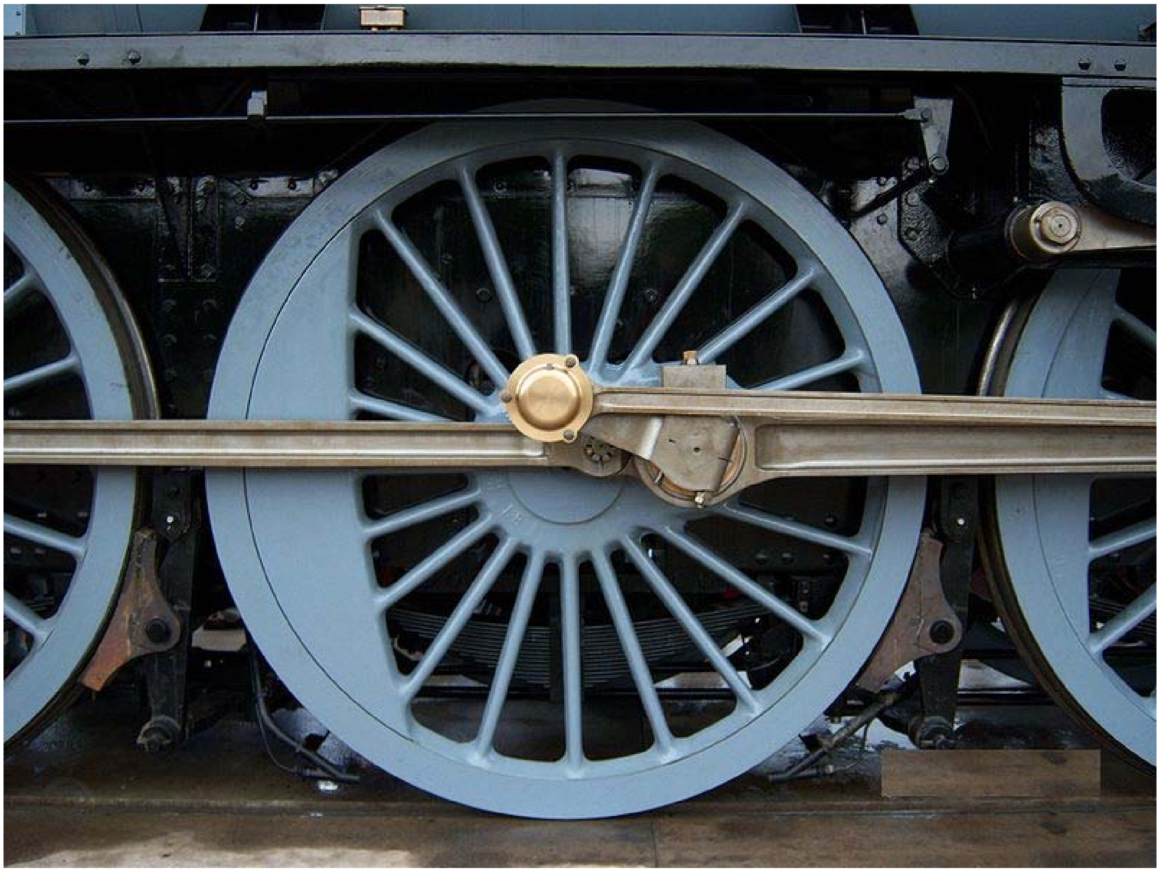
The four driving wheels on one side of a 4-8-4 locomotive.

On a steam locomotive, a **driving wheel** is a powered wheel which is driven by the locomotive's pistons (or turbine, in the case of a steam turbine locomotive). On a conventional, non-articulated locomotive, the driving wheels are all coupled together with side rods (also known as coupling rods); normally one pair is directly driven by the main rod (or connecting rod) which is connected to the end of the piston rod; power is transmitted to the others through the side rods.

On Diesel and Electric locomotives the driving wheels may be directly driven by the traction motors. Coupling rods are not usually used, and it is quite common for each axle to have its own motor. Jackshaft drive and coupling rods were used in the past (e.g. in the Swiss Crocodile locomotive) but their use is now confined to shunting locomotives.

On an articulated locomotive or a duplex locomotive driving wheels are grouped into sets which are linked together within the set.

Diameter



One of six 6 ft 8 in (2.03 m) driving wheels belonging to 60163 *Tornado*

Driving wheels are generally larger than leading or trailing wheels. Since a conventional steam locomotive is directly driven, one of the few ways to 'gear' a locomotive for a particular performance goal is to size the driving wheels appropriately. Freight locomotives generally had driving wheels between 40 and 60 inches (1,016 and 1,524 mm) in diameter; dual-purpose locomotives generally between 60 and 70 inches (1,524 and 1,778 mm), and passenger locomotives between 70 and 100 inches (1,778 and 2,540 mm) or so. Some long wheelbase locomotives (four or more coupled axles) were equipped with **blind drivers.** These were driving wheels without the usual flanges, which allowed them to negotiate tighter curves without binding.

The driving wheels on express passenger locomotives have come down in diameter over the years, e.g. from 8 ft 1 in (2,464 mm) on the GNR Stirling 4-2-2 of 1870 to 6 ft 2 in (1,880 mm) on the SR Merchant Navy Class of 1941. This is because improvements in valve design allowed for higher piston speeds.

Balancing

A driving wheel on a steam locomotive.

On steam locomotives the driving wheels have balance weights to balance the weight of the coupling and connecting rods. The crescent-shaped balance weight is clearly visible in the picture on the right.

Whyte notation

In the Whyte notation, driving wheels are designated by the middle number or numbers in the set. The UIC classification system counts the number of axles rather than the number of wheels and driving wheels are designated by letters rather than numbers. The suffix 'o' is used to indicate independently powered axles.

The number of driving wheels on locomotives varied quite a bit. Some early locomotives had as few as two driving wheels (one axle). The largest number of total driving wheels was 24 (twelve axles) on the 2-8-8-8-2 and 2-8-8-8-4 locomotives. The largest number of coupled driving wheels was 14 (seven axles) on the ill-fated AA20 4-14-4 locomotive.

Other uses of the term driving wheel

The term **driving wheel** is sometimes used to denote the **drive sprocket** which moves the track on tracked vehicles such as tanks and bulldozers.

Chapter 14

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.

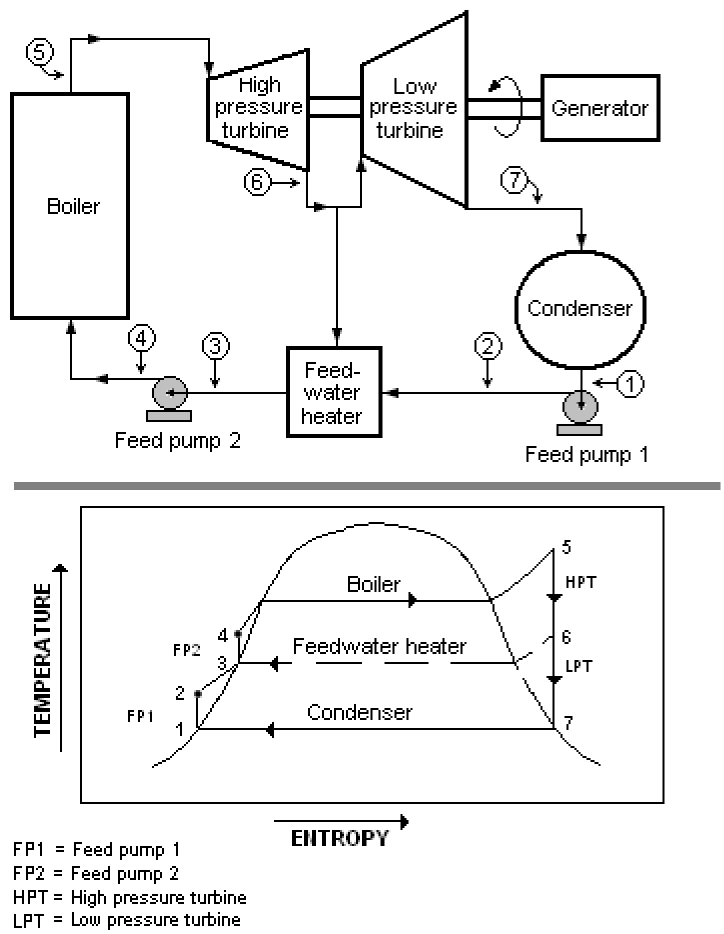
Hydrodynamic braking

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.

Chapter 15

Feedwater Heater and Giesl Ejector

Feedwater heater



A Rankine cycle with two steam turbines and a single open feedwater heater.

A **feedwater heater** is a power plant component used to pre-heat water delivered to a steam generating boiler. Preheating the feedwater reduces the irreversibilities involved in steam generation and therefore improves the thermodynamic efficiency of the system. This reduces plant operating costs and also helps to avoid thermal shock to the boiler metal when the feedwater is introduced back into the steam cycle. Many of the locomotive systems are **ACFI** type.

In a steam power plant (usually modeled as a modified Rankine cycle), feedwater heaters allow the feedwater to be brought up to the saturation temperature very gradually. This minimizes the inevitable irreversibilities associated with heat transfer to the working fluid (water).

Cycle discussion and explanation

The energy used to heat the feedwater is usually derived from steam extracted between the stages of the steam turbine. Therefore, the steam that *would be used* to perform expansion work in the turbine (and therefore generate power) is not utilized for that purpose. The percentage of the total cycle steam mass flow used for the feedwater heater is termed the extraction fraction and must be carefully optimized for maximum power plant thermal efficiency since increasing this fraction causes a decrease in turbine power output.

Feedwater heaters can also be *open* and *closed* heat exchangers. An open feedwater heater is merely a direct-contact heat exchanger in which extracted steam is allowed to mix with the feedwater. This kind of heater will normally require a feed pump at both the feed inlet and outlet since the pressure in the heater is between the boiler pressure and the condenser pressure. A deaerator is a special case of the open feedwater heater which is specifically designed to remove non-condensable gases from the feedwater.

Closed feedwater heaters are typically shell and tube heat exchangers where the feedwater passes throughout the tubes and is heated by turbine extraction steam. These do not require separate pumps before and after the heater to boost the feedwater to the pressure of the extracted steam as with an open heater. However, the extracted steam (which is most likely almost fully condensed after heating the feedwater) must then be throttled to the condenser pressure, an isenthalpic process that results in some entropy gain with a slight penalty on overall cycle efficiency.

Many power plants incorporate a number of feedwater heaters and may use both open and closed components.

Feedwater heaters are used in both fossil- and nuclear-fueled power plants. Smaller versions have also been installed on steam locomotives, portable engines and stationary engines. An economiser serves a similar purpose to a feedwater heater, but is technically different. Instead of using actual cycle steam for heating, it uses the lowest-temperature flue gas from the furnace (and therefore does not apply to nuclear plants) to heat the water before it enters the boiler proper. This allows for the heat transfer between the furnace and the feedwater to occur across a smaller average temperature gradient (for the steam generator as a whole). System efficiency is therefore further increased when viewed with respect to actual energy content of the fuel.

Giesl ejector

Steam locomotive with Giesl flat ejector

Austrian 0-12-0T and 0-6-2T fitted with Giesl ejectors, Eisenerz depot, August 1971

A **Giesl ejector** is a suction draught system for steam locomotives that works on the same principle as a feedwater pump.

This ejector (German: *Ejektor*, *Flachschornstein* or *Quetschesse*) was invented in 1951 by the Austrian engineer, Dr. Adolph Giesl-Gieslingen. The Giesl ejector ensures improved suction draught and a correspondingly better use of energy. The existing blastpipe in a locomotive is replaced by several, small, fan-shaped, diverging blast pipes, from which the diffuser gets its flat, long, drawn-out shape.

Giesl claimed that his ejector enabled a saving in coal of between 6 and 12 % – although in practice the maximum saving was more like 8 % – and an increase in power of up to 20 %. Many railway administrations converted their steam engines to Giesl ejectors, including the ÖBB, ČSD and Deutsche Reichsbahn (DR) in East Germany, as well as railway companies in Africa, China and Japan. The licence fees were not paid in every case, it being said that often they almost cancelled out the saving in coal. In the DR it was assessed that the Giesl ejectors would pay for themselves within a year, as a result of which they converted over 500 locomotives; primarily the Classes 38.10, 50, 52 and 65.10.

Use in the United Kingdom

Ejector from *Edward Thomas*, on display in the Narrow Gauge Railway Museum

In 1958, Dr Giesl-Gieslingen approached British Railways to offer a free trial of the ejector. When this offer was turned down, the inventor made the same offer to the preserved Talyllyn Railway in Wales, and locomotive No. 4, *Edward Thomas* was fitted with one. Although a coal saving of 40% was officially announced at the time, this has since been disputed by the railway's chief engineer. The ejector was removed in 1969, and no difference in coal consumption was found. The ejector is now on display in the Narrow Gauge Railway Museum at Tywyn.

In 1962, Bulleid Battle of Britain class 4-6-2 34064 *Fighter Command* was fitted with a Giesl ejector on the grounds that a desired spark arrestor would "suffocate" an ordinary blastpipe. It quickly became apparent, following some adjustment, that the ejector improved the locomotive design, and it was held in high regard by the crews. As a consequence of this experience and for the same reasons, during the 1980s the preserved Bulleid West Country class 4-6-2 34092 *City of Wells* was similarly fitted at the Keighley and Worth Valley Railway.

A BR Standard Class 9F 2-10-0 92250 was also fitted with a Giesl ejector, but with "indifferent" results.

Chapter 16

Long Hood and Leading Wheel

Long hood

The **long hood** of a hood unit-style diesel locomotive is, as the name implies, the longer of the two hoods (narrower sections of the locomotive body in front and behind of the cab) on a locomotive.

Equipment

The long hood normally contains the diesel engine (prime mover), the main generator or alternator, the locomotive's cooling radiators, the dynamic brake resistor grids if fitted, and most of the locomotive's auxiliary equipment. Head-end power equipment, if fitted, is normally in the long hood; steam generators for heating older passenger cars may be either in the long or short hoods.

Operating direction

Normally, the long hood is the rear of the locomotive. For early hood unit models, this was not the case; railroads preferred to have the long hood at the front and the cab at the rear, as in a steam locomotive; this followed crew preference for greater protection in a collision. Later, preferences changed to having the short hood at the front and the long hood at the rear, for better visibility, especially when more powerful engines required larger, visibility-obscuring radiator units.

United States

A Norfolk Southern GP38-2 operating long hood forward through Ridgewood, New Jersey.

The railroads that held out the longest for long-hood leading were the Norfolk and Western Railway and the Southern Railway (later merged into the Norfolk Southern). When Southern Railway received their first EMD GP7s, they were delivered with a high, short hood, and Southern Railway pointed the locomotive LHF for crew safety. After the first GP7s hit the Southern Railway System, subsequent locomotives were ordered with the high, short hood and the long hood designated (starting after the SD45 order) as the front. Here is a list of each locomotive Southern ordered with a high, short hood, and operated LHF.

General Motors Electro-Motive Division

- GP7,
- GP9,
- GP18,
- GP38,
- GP38-2,
- GP40X (SOU 7000-7002),
- GP49 (SOU 4600-4605),

- GP50 (SOU 7003-7092),
- SD7,
- SD9,
- SD35,
- SD40,
- SD40-2,
- SD45

(note: the SD50 and the GP59 are the first units ordered with the low, short hood, and pointed LHF)

General Electric Transportation Systems

- B30-7,
- U23B,
- B23-7,
- U30C,
- U30B,
- U33C,

The Norfolk and Western Railway (NW) operated as Southern Railway did, with the long hood toward the front; the only difference between NW locomotives and the Southern Railway locomotives was the position of the bell. NW had the bell on the short hood while Southern had the bell on the long hood.

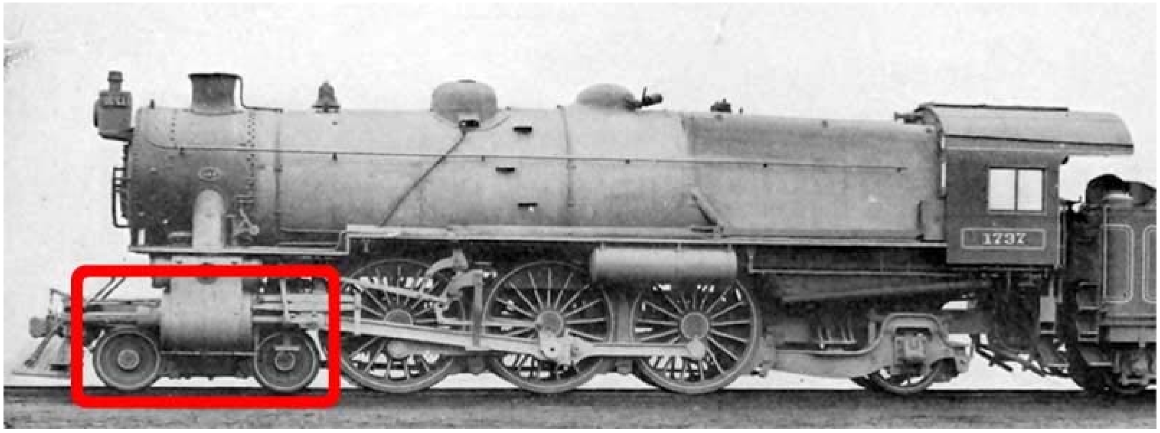
It should also be noted that many early diesel locomotive builders designated the long hood end of their road switchers as the front. Examples include models manufactured by the American Locomotive Company and Baldwin Locomotive Works.

Long hood forward is a fading practice. Most modern production of locomotives in the USA feature wide cabs, which bar the ability to run the unit LHF because most modern production locomotives have desktop style controls. The desktop style prevents the engineer from turning in his or her chair to face the other end of the locomotive.

Great Britain

The term Long hood forward is not used in Britain and the hood would be described as a "bonnet" or "engine compartment". Most British diesel locomotives have a cab at each end so the term does not apply. Where a single-cab design was used it was designed to be operated long hood forward but, in practice, it might operate in either direction, like a steam tank locomotive. Apart from shunters, the only single-cab class still in service in Britain is the British Rail Class 20. These are now usually operated cab forward (often in pairs) to give the driver a better view of the road ahead and some have been fitted with nose-mounted video cameras for use when working long hood forward.

Leading wheel



The leading wheels (boxed) on a 4-6-2 locomotive

The **leading wheel** or **leading axle** of a steam locomotive is an unpowered wheel or axle located in front of the driving wheels. The axle or axles of the leading wheels are normally located in a truck (or "bogie"). Leading wheels are used to help the locomotive negotiate curves and to support the front portion of the boiler.

Importantly, the leading bogie does not have simple rotational motion about a vertical pivot, as might first be thought. It must also be free to slip sideways to a small extent (otherwise the locomotive is unable to follow curves accurately – a point lost on the 19th century railway pioneers), and some kind of springing mechanism is normally included to control this movement and give a tendency to return to centre. The sliding bogie of this type was patented by William Adams in 1865. The first use of leading wheels is commonly attributed to John B. Jervis who employed them in his 1832 design for a locomotive with four leading wheels and two driving wheels (a type that became known as the *Jervis*). In the Whyte system of describing locomotive wheel arrangements, his locomotive would be classified as a 4-2-0: that is to say, it had four leading wheels, two driving wheels, and no trailing wheels. In the UIC classification system, which counts axles rather than wheels and uses letters to denote powered axles, the *Jervis* would be classified 2-A.

Locomotives without leading trucks are generally regarded as unsuitable for high speed use. The British Railway Inspectorate condemned the practice in 1895, following an accident involving two 0-4-4s at Doublebois, Cornwall, on the Great Western Railway. Other designers, however, persisted with the practice and the famous 0-4-2 Gladstone class passenger expresses of the London, Brighton and South Coast Railway remained in trouble-free service until 1933. A single leading axle (known as a pony truck) increases stability somewhat, while a four-wheel leading truck is almost essential for high-speed operation.

The highest number of leading wheels on a single locomotive is six as seen on the 6-2-0 Crampton type and the Pennsylvania Railroad's 6-4-4-6 S1 duplex locomotive and 6-8-6 S2 steam turbine. Six-wheel leading trucks were not very popular. The Cramptons were built in the 1840s, but it wasn't until 1939 that the PRR used one on the S1.