Vehicle Suspension Systems

Introduction

Almost all railway vehicles use bogies (trucks in US parlance) to carry and guide the body along the track. Bogie suspension design is a complex and difficult science which has evolved over many years. Some of the significant steps in progress are described here. See also [Wheels and Bogies](), [Bogie Parts]() and [Coach Parts]() pages.

Development

It was recognised very early in the development of railways that the interface between vehicle body and wheel needed some sort of cushion system to reduce the vibration felt as the train moved along the line. This was already part of road coach design and took the form of leaf (laminated) steel springs mounted on the axles, upon which the vehicle body rested. Railways in the UK used the same principle, as shown in Figure 1:.

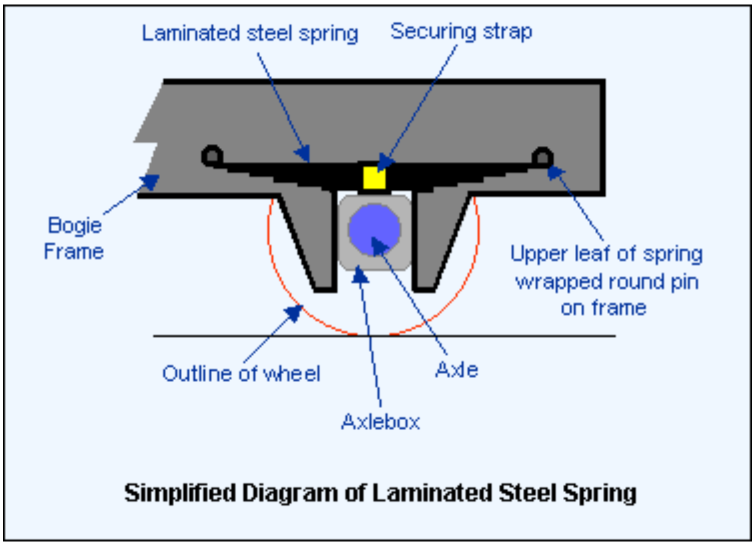

Figure 1: Traditional laminated steel suspension as applied to axlebox. Diagram: Author.

The spring consisted of a set of different length steel plates arranged with the longest at the top and the shortest at the base of the set. They were held together with a steel strap in the centre. This strap formed the point of contact with the axlebox. The laminations or "leaves" of steel gave rise to the "leaf spring" name more commonly used today. They were also referred to as"elliptical" springs, on account of the curved shape they often formed.

The top steel plate of the spring was secured to the vehicle underframe by having the ends wrapped round steel pins. The pins, two for each spring assembly, were fixed to the underframe. When mounted on the wheelset, the vehicle body weight was transmitted through the pins and the laminated steel spring to the axlebox.

The axlebox was only allowed vertical movement, since it was restrained by two "horns" extending down from the underframe. The horns had "horn guides" (not shown) to ensure security and to prevent twisting.

Plate Frame Bogie Primary Suspension

The natural progression from the rigid framed vehicles used in the early days of European railways to a bogie vehicle brought with it a more sophisticated suspension system. This system was based on a steel plate framed bogie with laminated spring axlebox suspension, much as seen on the first vehicles, and with a secondary suspension added between the car body and the bogie. First, we look at the primary suspension.

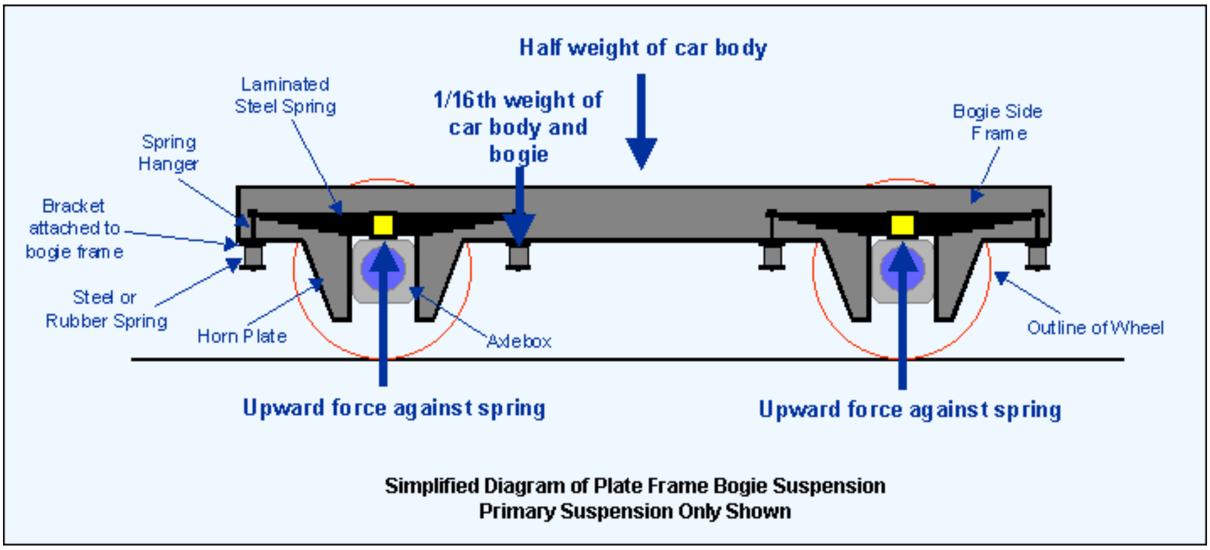

Figure 2: Sketch of plate frame bogie primary suspension system. Diagram: Author.

The diagram above (Figure 2) shows a plate framed bogie with the primary, axlebox suspension. The secondary, bolster suspension is left out for simplicity. The bogie carries half the car weight which is then divided roughly equally between the two axles. If we said the whole vehicle weight was 30 tonnes, each bogie would carry 15 tonnes and each axle 7.5 tonnes. For a civil engineer wanting to know the stresses on his structures and track, we would tell him we had a 7.5 tonne axle load. Of course, we would include the carrying load of passengers and freight in this calculation.

Returning to the primary suspension design, we see that the laminated axlebox spring is fitted with two "spring hangers" attached to the outer ends of the longest spring plate. Each hanger passes through a hole in a bracket attached to the bogie frame and is screwed into another bracket at the bottom end. Between the two brackets is a steel or rubber spring. The weight of the bogie on the axlebox is transmitted through the steel laminated spring and the two spring hangers. Each spring hanger and its associated spring carries 1/16th of the total car weight. The height of the bogie relative to the rail level could be adjusted by using the screwed spring hangers. The adjustment allowed for small variations in wheel diameter.

Plate Frame Bogie Secondary Suspension

The secondary suspension of the bogie is mounted crosswise (transversely) in the centre. End on, it looks as shown below Figure 3. The bogie has a pair of transverse members called "transoms". They are riveted or welded (depending on the design) to the bogie side frames. A steel "swing link" is hung from each end of each transom and a spring plank is laid across the bogie between them.

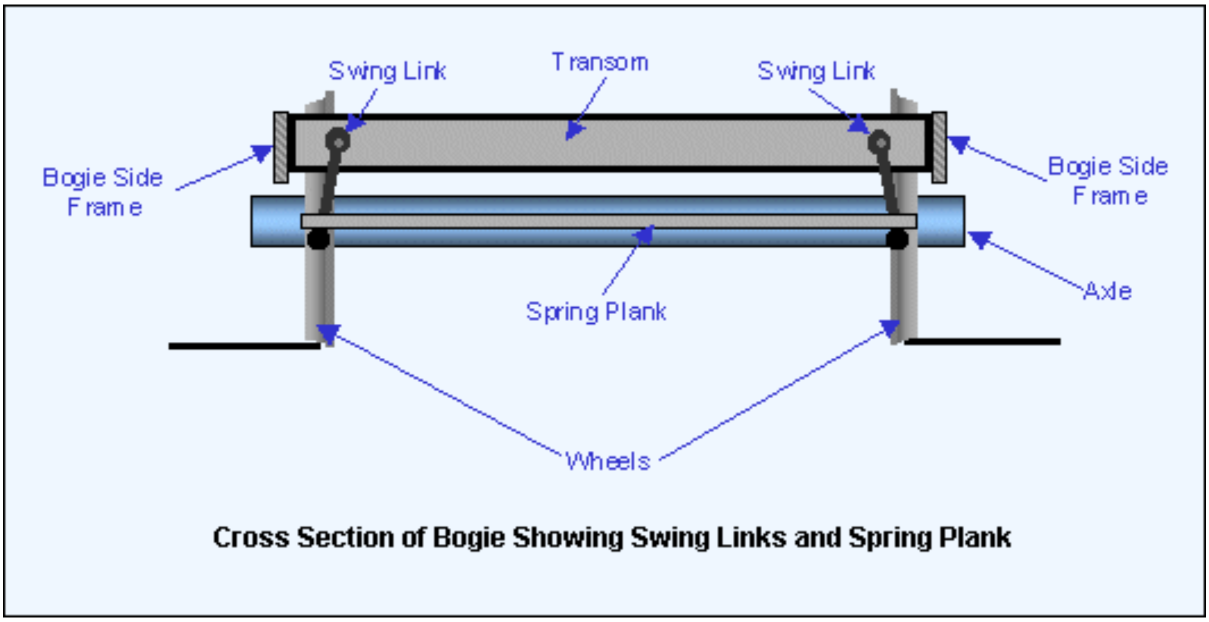

Figure 3: Transverse section of bogie frame with spring plank suspended on swing links. Diagram: Author.

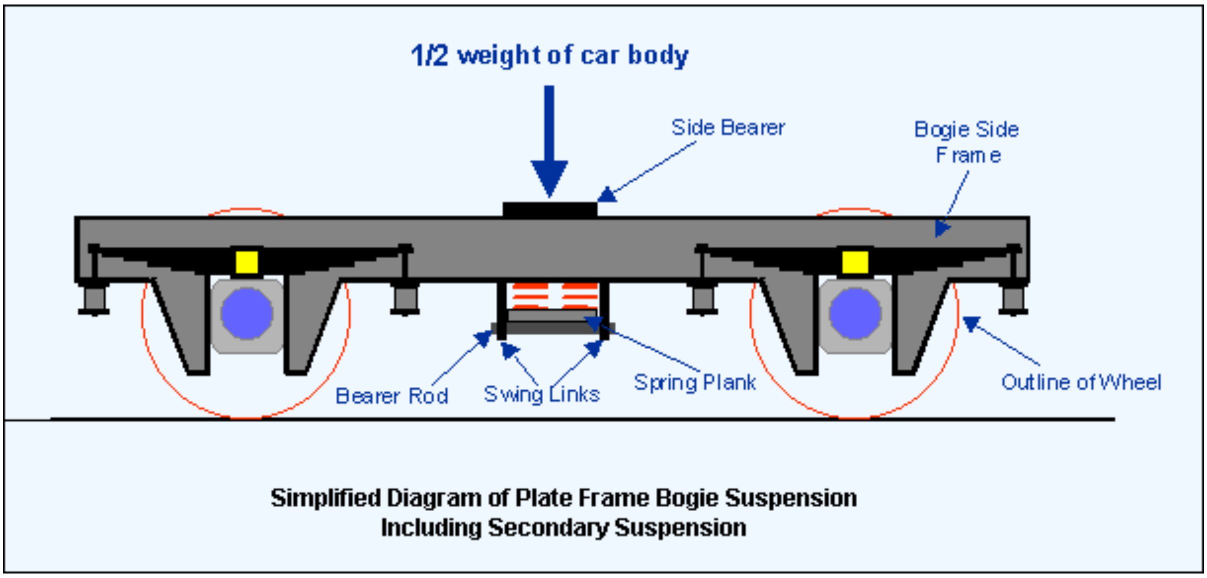

Figure 4: A side view of the bogie shows the way the spring plank is supported by the swing links.

The spring plank rests on bearer rods suspended between the swing links. This arrangement allows the spring plank to rock from side to side and it will act in opposition to sideways movement of the bogie frame. The spring plank, as its name suggests, carries springs, as shown in the next diagram.

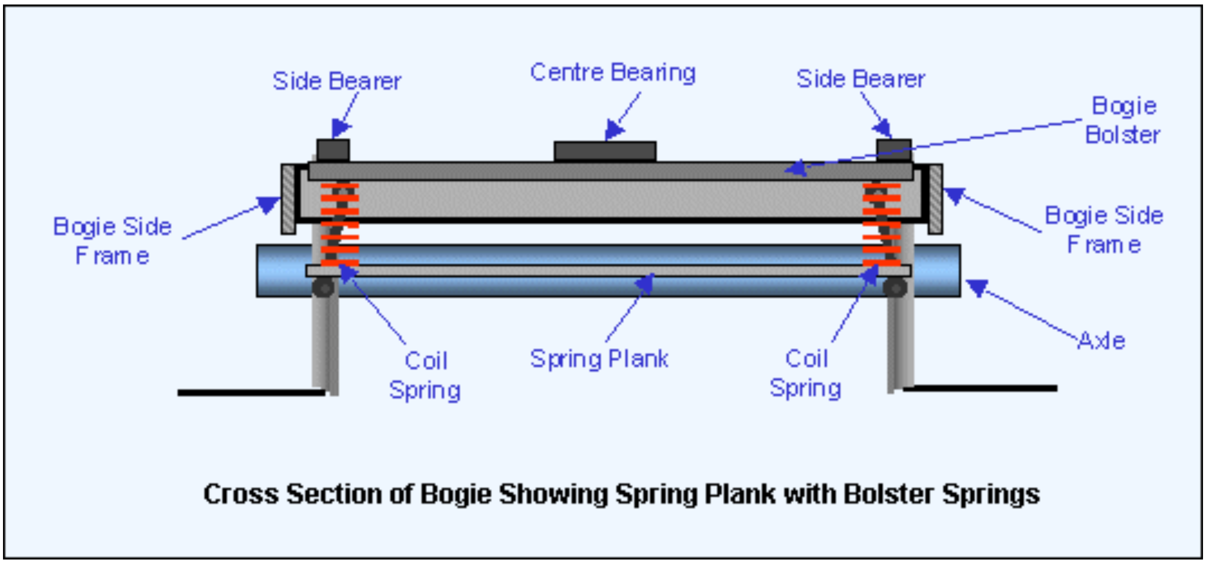

Figure 5: View of transverse section od bogie showing spring plank with bolster springs. Diagram: Author.

A pair of steel coil springs (Figure 5, shown in red) rest on each end of the spring plank. On top of them sits the bogie bolster. The bolster carries the vehicle body. The body is located by a centre bearing, using a pin fitted to the underframe of the body and steadied by two side bearers. The side bearers are flat to allow the body to slide on the bearer so that the bogie can turn about the centre pin.

This type of arrangement began to be replaced by more modern designs from the 1960s but it is still common around the world and there are many variations. Nevertheless, the basic principles of primary and secondary suspension on bogies are standard throughout.

Cast Steel Bogies

In the US, cast steel was the most popular material for bogies and a simple basic design evolved as we can see in the diagram below, Figure 6.

In its simplest form, as used under the standard American freight car, sprung suspension was only provided for the bolster. The bogie consisted of three main parts - the bolster and the two side frames. The basic arrangement provided for a set of steel coil springs provided inside an opening in each side frame of the bogie. The bogie bolster (truck bolster in the US) was mounted on top of these springs and held in place by guides cast into or bolted onto the bolster. The axleboxes were not sprung and merely slotted into the frame, which rested directly on them. The ride wasn't soft but it was adequate. Some later versions of this truck have axlebox springs - simple coil springs inserted between the top of the axlebox and the truck frame.

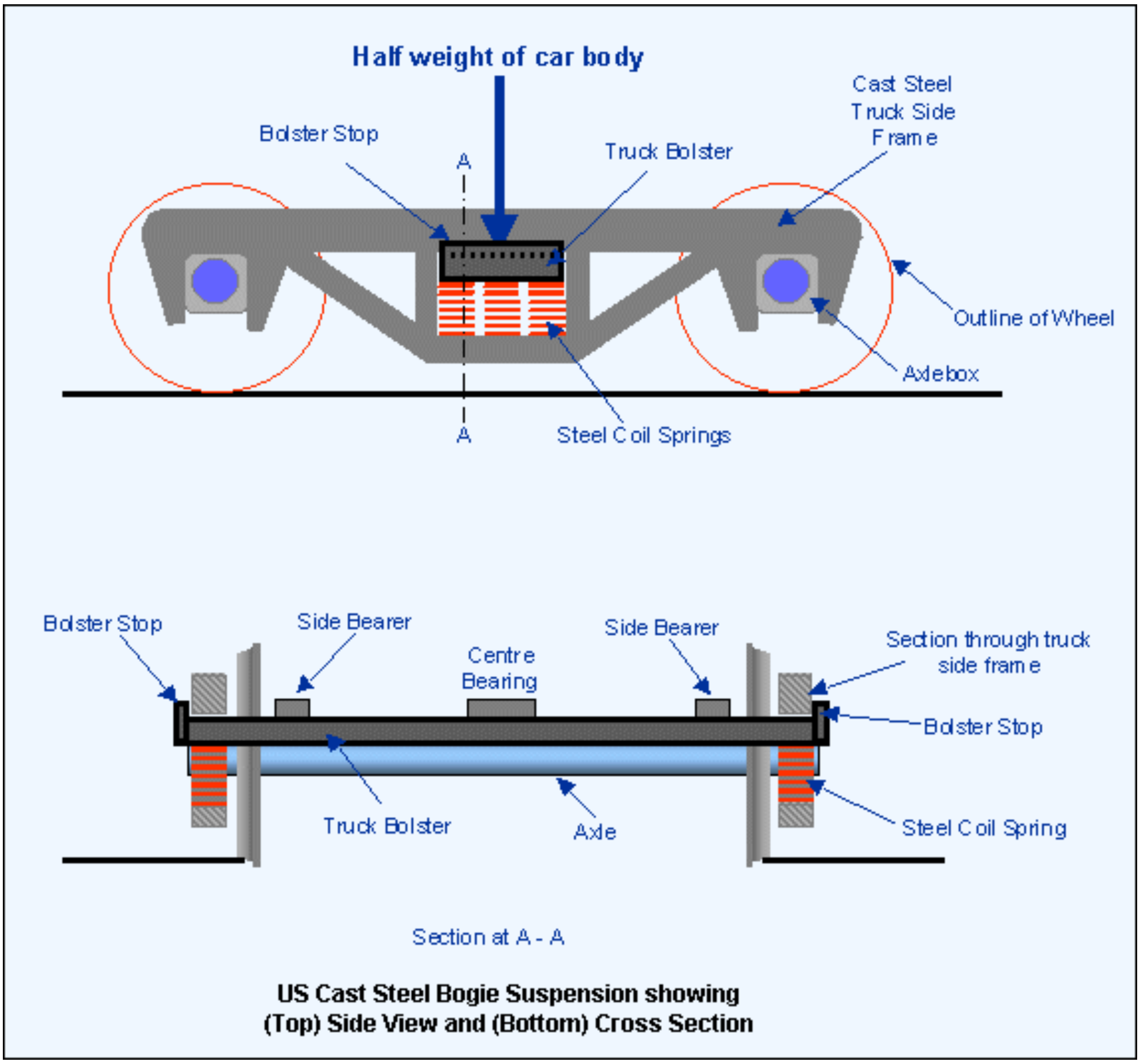

Figure 6: Cast steel bogie frame for freight car. Diagram Author.

Of course, nothing is a simple as it looks as first sight. So it is with the US freight truck, which is actually a bit more complicated than seen above. If you bear in mind that a freight car can become five times heavier when it is loaded than when it is empty, it becomes clear that the suspension must be stronger to carry the load. The US type has a second set of bolster springs as shown in Figure 7 below.

The second set of springs only comes into contact with the truck bolster when it is depressed by the extra weight loaded on the vehicle. The loaded springs are stiffer than the empty springs so that the stability is maintained regardless of the load applied. These loaded springs are normally fitted with friction blocks (not shown for simplicity) on top to allow proper alignment and to regulate the reaction of the spring to the load.

Freight bogies in Europe and UK are also fitted with load compensation systems using double springs and friction damping devices but they are usually more complex than the simple US design.

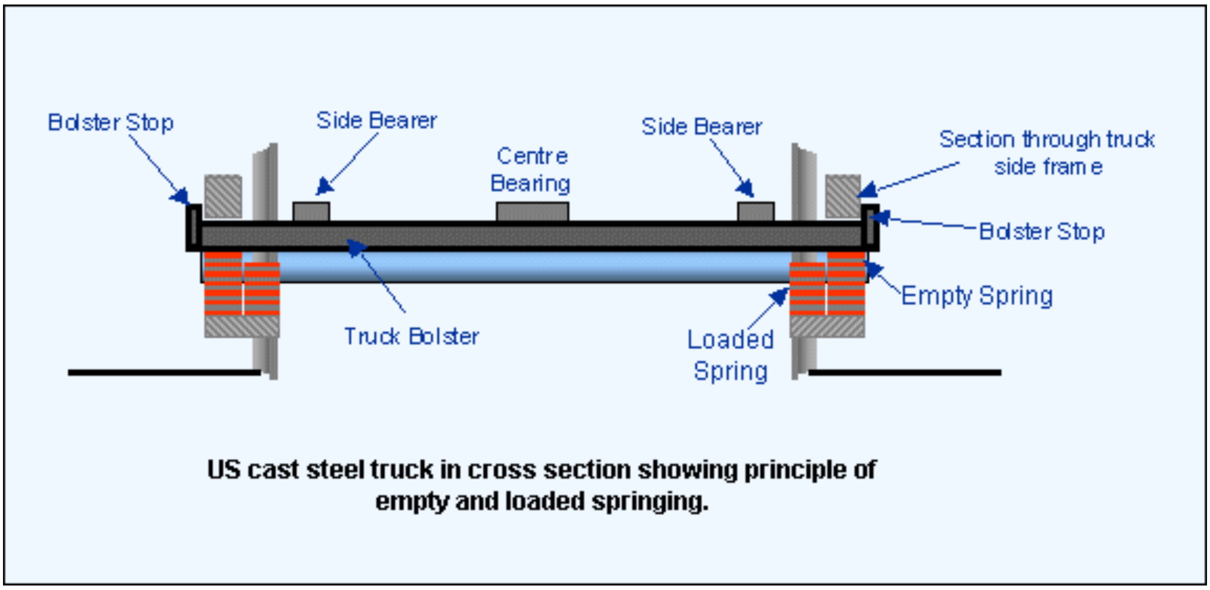

Figure 7: US Cast steel truck in section showing the arrangement of empty and loaded springing. Drawing: Author.

Equaliser Bar Suspension

A design popular in the US was the equaliser bar truck, which we can see in the following simplified diagram (Figure 8). It was also known as the Commonwealth Bogie.

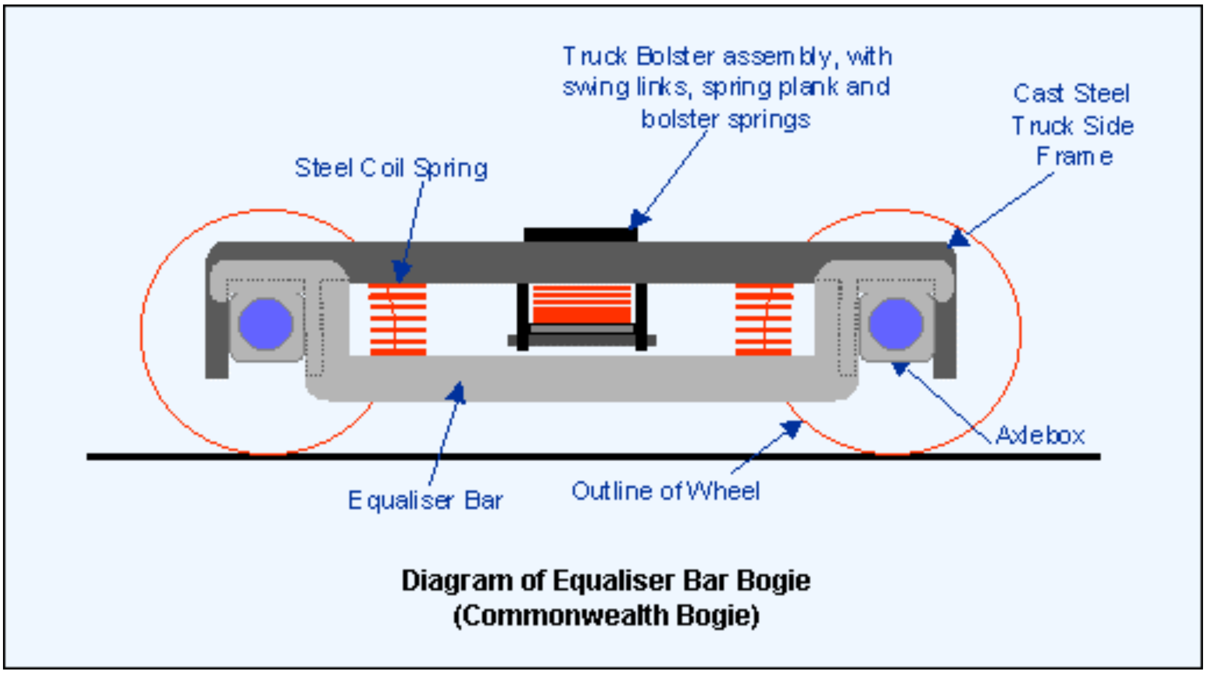

Figure 8: Diagram of equaliser bar bogie. Diagram: Author.

The side frame of the bogie was usually of bar construction, with simple horn guides attached, allowing the axleboxes vertical movements between them. The axleboxes had a cast steel equaliser beam or bar resting on them. The bar had two steel coil springs placed on it and the truck frame rested on the springs. The effect was to allow the bar to act as a compensating lever between the two axles and to use both springs to soften shocks from either axle. The truck had a conventional bolster suspension with swing links carrying a spring plank. In a reversal of British practice, the equaliser bar truck had leaf springs supporting the bolster and coil springs acting as the primary suspension.

Rubber Suspension

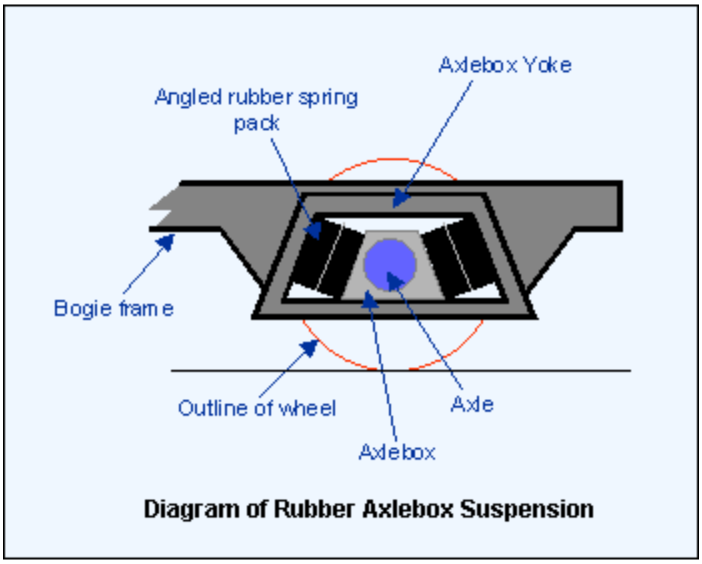

Figure 9: Rubber axlebox suspension system. Drawing: Author.

Steel springs provide a solid and reliable cushion for vehicle suspension but steel is heavy and requires maintenance because of wear and rust. Rubber however, if it could be produced with sufficient strength and durability, could perform the same function and it was used for minor parts of steel suspension systems from the late 19th century. Then, in the 1950s, some EMU trains were equipped with rubber packs replacing the steel in both primary and secondary suspension positions.

The axlebox is specially shaped, as shown here, to allow the fitting of rubber packs at an angle which will allow the forces to be transmitted to the bogie frame. In some designs used by the London Underground for many years, a cast steel yoke was provided to carry the axlebox and rubber chevrons which formed the suspension packs. The yoke was adjustable (not shown) relative to the bogie frame to permit some variation in its position to compensate for wheel wear.

Bolster suspensions were also redesigned at this time to allow rubber to be used instead of steel. Angled rubber packs, shaped like chevrons like the axlebox suspension, replaced the traditional steel springs and were quite successful until they were superseded in later designs by air springs.

Although successful in lighter applications, rubber suspensions can require careful design to be an effective and reliable alternative to steel because sometimes strange effects on other parts of a train can appear. One well documented case, in London Underground, describes how the performance of traction motor brushes deteriorated when rubber suspension was introduced in the early 1960s. Extensive trials were needed before the cause and the cure, a modified form of motor brush tension spring, was finally discovered.

Air Suspension

It was only a matter of time before trains began using compressed air in their suspension system. They first appeared in the 1960s and were considered somewhat of a novelty at the time but, nowadays, air suspension is a standard fitting for passenger vehicles.

Apart from the provision of a better ride, air suspension has one additional feature rare on conventional steel or rubber suspension systems - the ability to provide an accurate load/weight signal which can be used to modify the acceleration and braking of a multiple unit train. A diagrammatic arrangement of an air sprung bogie is shown below (Figure 10).

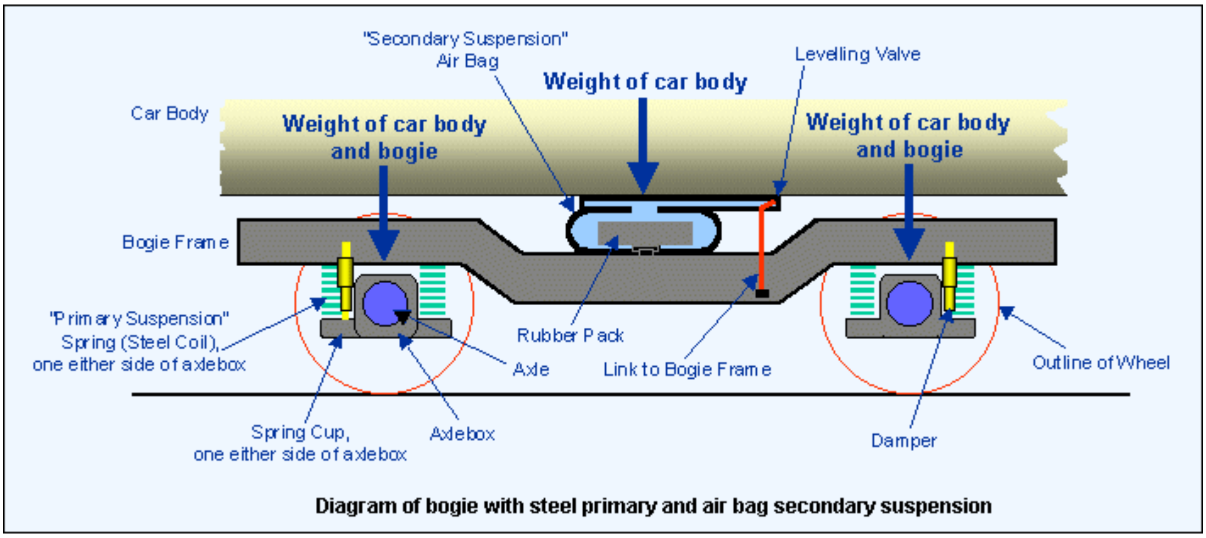

Figure 10: A passenger coach bogie with steel coil primary and air bag secondary suspension. Diagram: Author.

The weight of the car body (well, half of it, since the other half is carried by the other bogie) rests on the air bag, which is mounted on the top of the bogie frame. Compressed air is fed into the air bag through a levelling valve attached to the underside of the car body. The valve is operated by a lever attached to one end of a link, whose other end is fixed to the bogie frame. Any vertical movement between the car body and the bogie is detected by the lever which adjusts the levelling valve accordingly.

When the load on the car is changed at a station by passengers boarding and alighting, the weight of the body changes and the levelling valve adjusts the air pressure in the air bags to match. The effect is that the car body maintains almost a constant height from rail level, regardless of load. I say almost a constant height because the primary springs will depress to some degree with the additional load. If the car load is reduced, the levelling valve will allow excess air pressure to escape. This can sometimes be heard as an intermittent gentle hissing from under the cars at a terminus as all the passengers alight from a modern coach.

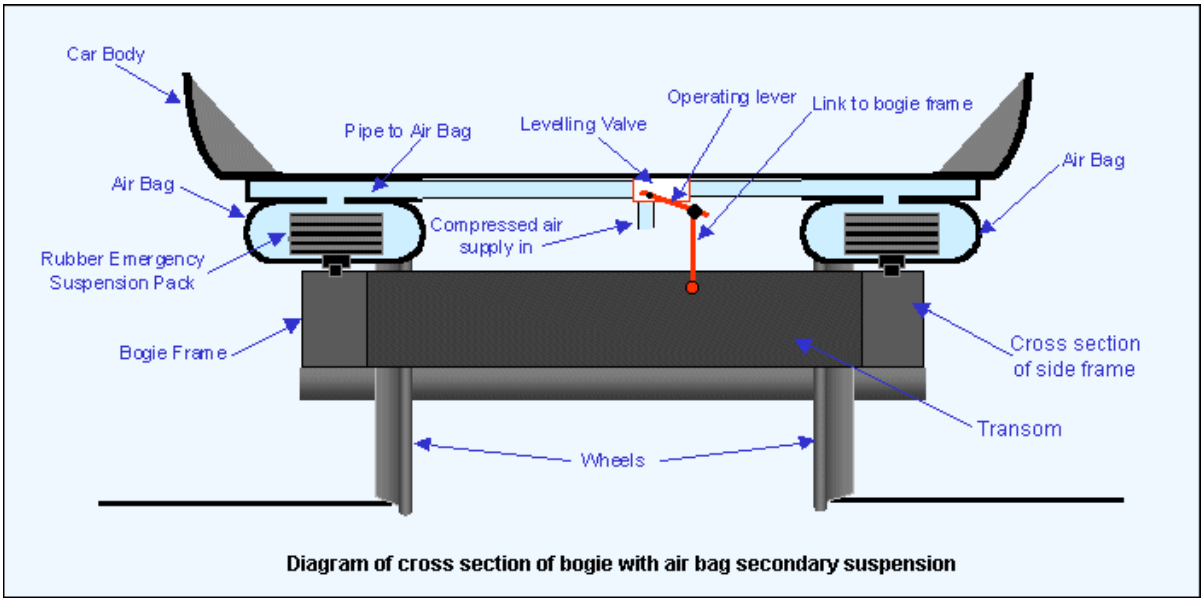

Figure 11: Cross section of bogie with air bag suspension.

In this transverse view of a car with air suspension, the two air bags provided on a bogie can be seen. Inside each is a solid rubber suspension pack sufficiently strong to carry the suspension load, retained in case the air bag should burst or the air supply is lost.

One other feature of air suspension systems is that they can only alter the air bag pressure when the train is stationary. Constant changes of vehicle height would cause excessive bouncing if the system operated while the train was running. The levelling valve is automatically locked out of use when the train is moving or when the doors are closed - depending on design.

This type of arrangement often uses a bolsterless truck or bogie, as shown is the diagrams above. It is a very simple design where the bogie frame is fabricated, usually in welded box-sections, into the form of the letter H. The crossbar of the H is where the bolster would be. It is called the transom. Instead of being suspended on springs it is solid with the side pieces. The car body (secondary) suspension is through the air bags mounted on the ends of the "crossbar" of the H. This type of bogie is now popular on passenger rolling stock.

This paper originally prepared as a web page for RTWP in 2004.