

# Brake System Comparison for European and North-American Heavy Vehicles



Dr Peter Hart. Peter is a consulting engineer and Chairman of the Australian Road Transport Suppliers Association (ARTSA).  
Email: pmhart@hartwood.com.au



Mr Les Bruza, Engineering Manager, is a mechanical engineer and is the Chief Engineer of the National Heavy Vehicle Regulator, Australia. Email: les.bruza@nhvr.gov.au

## Abstract

The paper provides a detailed comparison of the brake systems that are used on European and North American Heavy Vehicles. These systems have significantly different design features. The focus of this paper is on combination vehicles although the presentation is relevant to single trucks.

Brake testing was conducted on a specially modified truck-tractor that could be adjusted to model either North American or European brake characteristics. The results show that both types of truck-tractors in combination with a semi-trailer produce comparable and acceptable brake performance if the trailer has an adaptive brake system. An adaptive brake system is one that changes the brake capability on a vehicle in proportion to the load carried.

In a second series of tests, the performance of the roll-stability program (RSP) systems on a truck-tractor and on its semi-trailer were investigated. Most of the safety benefits of the RSP can be obtained with RSP on the truck-tractor only, as is proposed for new North American vehicles. However, this proposal does not ensure that adaptive brakes will be used on new North American trailers.

This information will be particularly important for any operator who has a mixed fleet of vehicles where both European- and North American-made vehicles are used with a shared trailer fleet. This situation occurs frequently in Australia.

**Keywords:** Heavy vehicle braking, combination vehicle braking, European braking system, North American braking system, heavy-vehicle braking rules, electronic stability control.

## **1. The Challenge of Heavy Vehicle Braking**

The purpose of a vehicle brake system is to control the speed of the vehicle in a safe manner. Safety requires achievement of both a relatively short stopping distance and directional control during heavy braking. In the past it has been the driver who had to find this balance. Intelligent braking systems can now assist the driver. Advanced systems can initiate and completely manage the braking event. Combination vehicles can have different brake control technologies on the different parts and this can result in sub-optimal performance, even when one part has an intelligent brake system. Compatibility of brake technologies is important.

The characteristics of the service brake system influences the performance of any brake control strategy. This paper describes the significant brake system differences that exist between heavy trucks designed in North-America and those designed in Europe.

The minimum stopping distance that a heavy combination vehicle can achieve is affected by both the capacity of the brake system and the available friction between the tyres and the roadway. In most instances the brakes can lock-up wheels, at which stage it is the available sliding road-tyre friction that limits the achievable stopping distance. Locked-up wheels cannot provide the usual lateral stabilizing forces and so wheel lock-up brings with it the risk of loss of directional control.

The directional stability of a vehicle during heavy braking is mainly determined by the distribution between wheels of the brake force per tonne of weight carried by the wheels. In practice, the minimum stopping distance that can be safely achieved depends upon both the brake system capability and the driver's confidence that the full capability can be applied. If the driver believes that directional control will be lost during heavy braking, he or she is unlikely to apply full brake effort. Intelligent brake controls can managed the braking event and thereby provide greater confidence to the driver that the vehicle will remain in control.

The principle of brake balance is that brake forces at the wheel ends should be in proportion to the weight carried at that wheel end. There are disturbing factors such as weight variation as the load changes and weight distribution changes due to load transfers during heavy braking. In particular, loads shift from rear axles to front axles and, when the trailer rests on the towing vehicle, from the trailer to the towing vehicle. Brake design rules may or may not require that these weight-force changes are compensated for.

## **2. International Harmonization of Braking Rules**

The great majority of countries have harmonized heavy vehicle braking rules with the international rule UN ECE Regulation 13. The European Union has based its rules on the UN ECE regulations since 1958 and consequently, Regulation 13 reflects European thinking. Other countries, such as Japan and more recently China can manufacture vehicles to comply with UN ECE Regulations. Many European test authorities offer certification services across the world (including in the USA) so it is now common for vehicle manufacturers to obtain UN ECE certificates for tests done in the country of manufacture.

The USA has no policy of harmonizing its rules with 'international rules'. The Canadian air-brake rule, CMVSS 121, is harmonized with the USA air-brake rule FMVSS 121. Both Canada and the USA are participants to the UN 1998 agreement and are contributing to development of Global Technology Rules. The USA has recently based FMVSS 126 (ESC

for light vehicles) on Global Technology Rule No 8; which has been developed by the UN ECE. Therefore there is slow movement towards global brake rules.

The USA has issued a notice of proposed rule-making that will require Electronic Stability Control (ESC) on new heavy truck-tractors and buses (proposed rule FMVSS 136). Trailers are not included. In contrast UN ECEC Regulation 13 requires that all heavy trucks, buses and trailers have an Electronic Stability Control System (ESC). The USA has not yet announced whether it will align FMVSS 136 with the ESC technical requirements in ECE Regulation 13.

Countries that have an open market for heavy motor vehicles, such as Australia, have to deal with the range of brake systems that occur on North American, European, Japanese,... motor trucks. Multi-combination vehicles (such as B-doubles, B-triples, A-triples and AB quad road-trains) are routinely used in Australia. The challenge that arises is to achieve acceptable brake performance when the brake systems on the truck tractor can differ substantially depending upon the country of manufacture.

There is another significant variation, which is that the foundation brake technology and the capacity of the brakes can differ between trailers in a multi-combination vehicle. Ultimately poor brake balance on a combination vehicle will result in dynamic instability during heavy braking. The number of variables that exist is beyond the capability of in-service brake rules to always produce acceptable outcomes, unless the design rules that the vehicles were manufactured to have very tight brake-balance requirements.

### **3. Brake Performance Basics**

#### **3.1 Weight Variation**

A significant disturbing factor affecting brake balance on a load-carrying commercial vehicle is weight variation. There are two effects, which are load transfer forward due to the height of the load being well above the axle level and secondly, the usual load variation between laden and unladen conditions.

For example, consider a semi-trailer that has a height to s-dimension ratio of 0.3 (e.g. s-dim = 8m and h = 2.4m), a total sprung weight of 30t; and an instantaneous deceleration of 0.4g. There is a transfer of 3.6t from the rear axle group to the front skid plate. Effectively a weight of 3.6t moves from the rear of the trailer to the front.

There is another weight variation that is even more significant. This variation occurs when the load on a commercial vehicle is changed. As a guide a heavy truck-tractor when in a semi-trailer combination, has a lightly-laden weight of 9 – 12 t. The semi-trailer has a tare weight in the range 6 – 9t. The fully-laden weight of a semi-trailer is likely to be 30 - 34 t and that of the truck-tractor 20 - 24t. The truck-tractor experiences a load variation between lightly-laden and fully-laden conditions of about 2:1 whereas the semi-trailer experiences a load variation of about 3:1. Consequently, a service-brake system that is ‘sized’ to give balance between the truck-tractor and trailer in the laden condition will be unbalanced in the unladen condition. The semi-trailer will be over-braked when lightly laden.

#### **3.2 Adaptive Braking**

In a perfect situation each wheel brakes the weight that it carries however, load variations that occur on a commercial vehicle, together with changes in weight distribution due to dynamic factors make it impossible to achieve perfect brake balance.

The brake forces that are generated by the foundation brakes are independent of the load level. Therefore, if balanced braking is to be achieved, the brake capability needs to change

with load level. That is the brakes must be ‘adaptive’. There are three types of adaptive brakes in common use which are:

1. Load-Sensing Brakes (LSB), for which the brake capability on selected axles is varied by air-valves (relay valves) in response to the load level.
2. Electronic Brake Distribution (EBD), which uses intelligent control to set the braking level in response to steady operating conditions.
3. Electronic Stability Control (ESC) that uses intelligent control and instantaneous performance information, to control the brake level at each wheel.

Load-Sensing Brakes respond to the steady load level and do not reset during a braking event. Electronic Brake Distribution also responds to a rear suspension deflection signal, which is a measure of the steady load level. Advanced EBD systems monitor the sensed-wheel speeds and set the EBD taking account of the history of the relative wheel speeds on the various sensed axles. Advanced electronic control systems such as ESC respond during each braking event taking account of the sensed-wheel speeds and other measures such as yaw accelerations and the steering wheel orientation. Therefore adaptive brake control can be divided into static and intelligent brake controls.

### **3.3 Road-Tyre Friction Levels**

The peak friction longitudinal friction between a rolling truck / trailer tyre and a sealed asphalt roadway is taken to be 0.9 (best case). When the wheel locks up, the longitudinal friction level drops to  $\sim 60\% \times 0.9 = 0.54$ . The lateral friction level under the same conditions is taken to be 0.8 for a rolling tyre falling to  $\sim 30\% \times 0.8 = 0.25$  when locked. Ultimately deceleration is limited by the peak road-tyre friction co-efficient that exists. There is much to be gained by avoiding tyre lock-up. An intelligent brake control that monitors the wheel speeds second-by-second might be able to achieve this. The loss of control that can occur mainly comes from locking up a truck tyre is the loss of lateral (stabilizing) force.

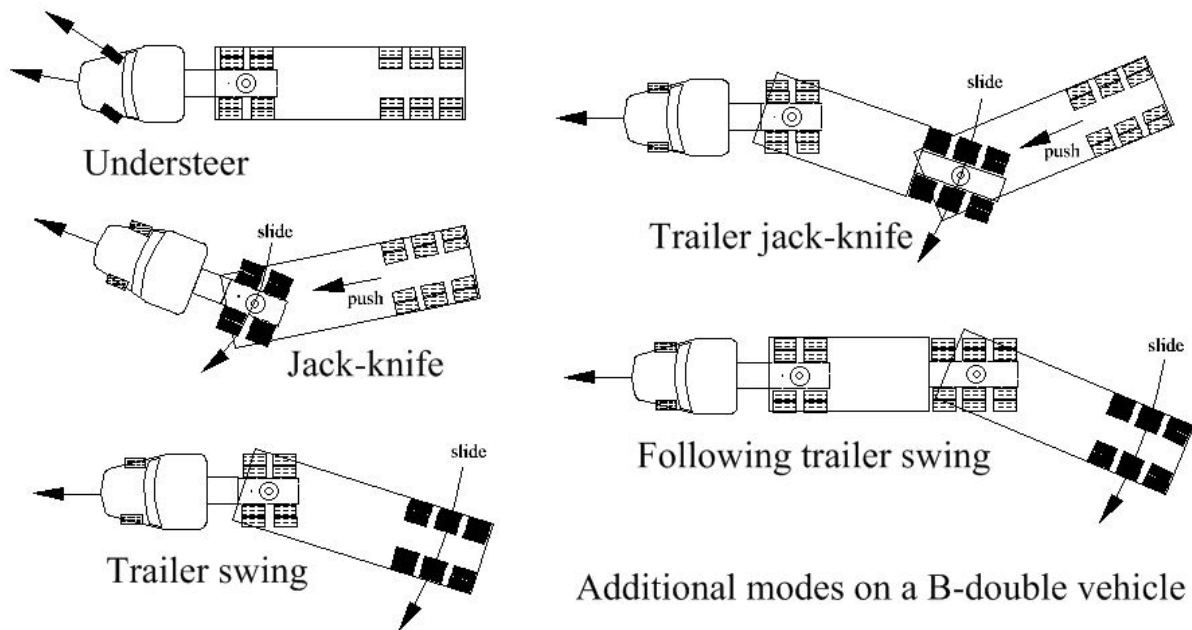
### **3.4 Dynamic Instability Modes**

The dynamic modes of vehicles need to be considered as the consequence of poor brake balance can be dynamic instability. Wheel lock-up on rear axles will probably lead to yaw motion which is directionally unstable. This is likely to be severe when there is a trailer pushing on the rear of the towing vehicle, leading to jack-knife. Lock-up on front axles does not lead to directional instability but it does render steering control ineffective. The optimum arrangement is then to achieve wheel lock-up on front and rear axles at about the same control level. The optimum arrangement is impossible to achieve without intelligent control.

The main instability modes of single and multi-combination vehicles are illustrated in Diagram 1. The design of a brake system needs to be informed by knowledge of the likely dynamic modes so that no one mode is dominant.

The black wheels have minimal ability to resist sideways dynamic forces. The risk that a vehicle might slew sideways during heavy braking is greatly increased when the brake capability is biased to the rear axle group. As will be discussed in Section 4, North American vehicles tend to have brake capacity biased to the rear axle groups. Therefore the challenge is to avoid jack-knife and trailer swing. European vehicles tend to have the brake capability biased forward. Therefore the challenge for European truck-tractors is to avoid understeer.

For multi-combination vehicles with two or three trailers, the use of brake control systems with substantially different characteristics on the different trailers, greatly increases the risk of the trailer dynamics shown on the right-side of Diagram 1 occurring.



**Diagram 1** Instability modes arising from wheel lock-up. Locked up wheels are shown black. Wheels shown with tread pattern are not locked-up.

### 3.5 Approaches to Brake Compatibility

*Brake Distribution Balance* is the extent to which the braking effort on each vehicle (measured as retardation force per axle / dynamic weight on the axle) is about the same.

*Brake Compatibility Balance* is the extent to which the braking effort of the different vehicles in a combination (measured as the total retardation force of the vehicle / total dynamic weight on the vehicles axles) is about the same.

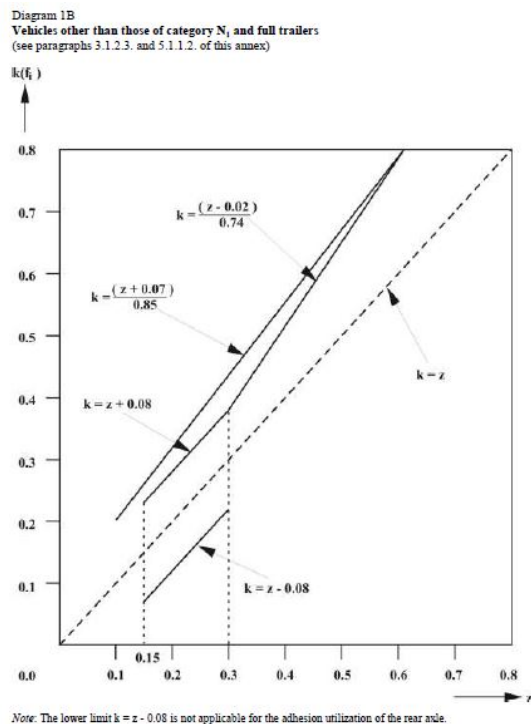
A vehicle with perfect brake balance will have the retardation forces at each axle proportional to the weight carried by that axle. In the ideal case, all wheels lock at the same control level and the maximum achievable deceleration is that set by the peak of the road-tyre friction curve. This is a theoretical level because brake balance is never perfect and operation at the peak of the friction curve is unstable.

The international brake rule UN ECE R13 contains both distribution and compatibility requirements. Diagram 2 shows the distribution requirements applicable to a two-axle truck-tractor. For a three-axle truck trailer, the front axle utilization must be higher than one of the rear-axle utilization curves for braking rates 0.15 – 0.3. Note that distribution requirements can be met by brake selection and air-system design.

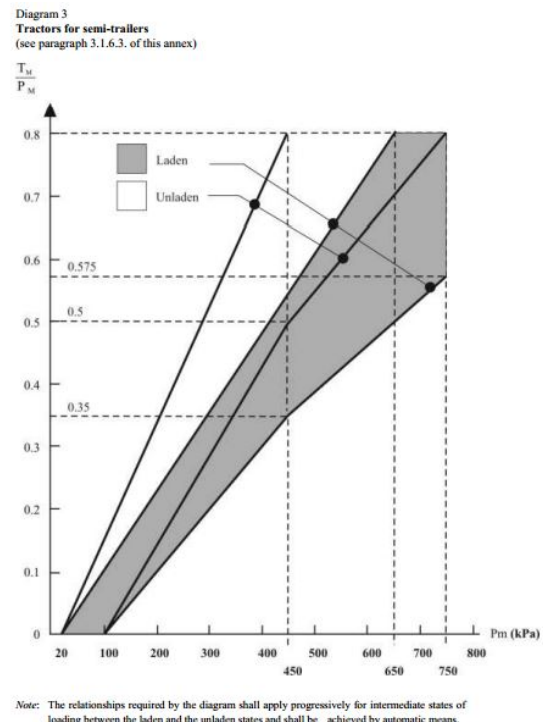
An intelligent or adaptive brake system is not necessary. The Regulation 13 distribution requirements are intended to minimize the risk of yaw-instability under heavy braking. There is no such requirement in the US rule FMVCS 121 and North American truck-tractors do not comply because the brake distribution is biased to the rear-axle group.

The compatibility limits in UN ECE R13 applicable to a truck-tractor are shown in Diagram 3. Because truck-tractors typically experience a weight change of 2:1 between laden and unladen states, the unladen compatibility limits can only be met using an adaptive brake system. Consequently there is a long history of load-sensing brakes being fitted to new European trucks and trailers. Compliance with the unladen limits was dropped for truck-

tractors and for trailers fitted with ABS / ESC. However, the European unladen limits have always been influential in the setting of Electronic Brake Distribution (EBD), which is a feature of current generation intelligent braking systems.



**Diagram 2** Adhesion utilization from UN ECE R 13 (vehicle with two axes).



**Diagram 3** Compatibility limits from R13 (truck-tractors).

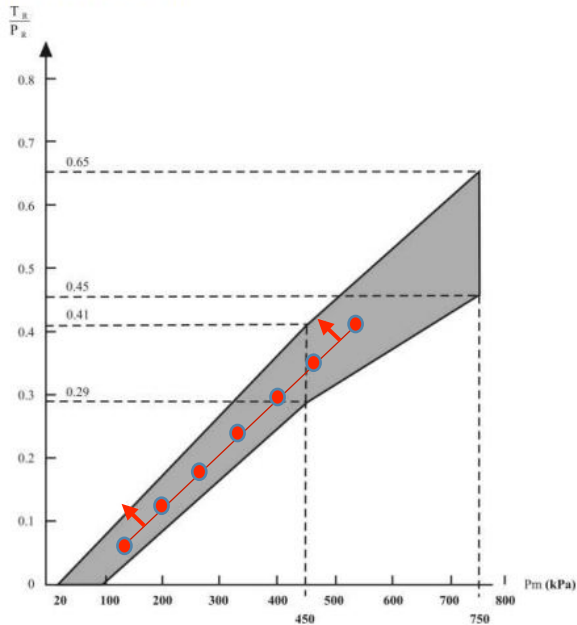
There is no brake compatibility requirement in the North American rules. The stopping distance requirements, which are considered in the following section, do provide a control on the unladen brake capability because the unladen stopping distances are to be proven whilst staying within a 12 ft lane width. This is difficult to achieve with very powerful rear brakes because of the tendency of the vehicle to slew under heavy braking. However, the performance depends upon the skill of the test driver.

The semi-trailer compatibility limits are derived from Diagram 4. These limits are modified by two factors  $K_c$  and  $K_v$  which depend upon dimensions of, and weight ratings of the semi-trailer. The semi-trailer limits reflect the fact that some semi-trailer weight is transferred to the towing vehicle during heavy braking. The extent of the transfer depends upon the load height relative to the trailer length, as discussed previously.

In practice, the applicable compatibility limits for a trailer at a given pressure are less than for the truck-tractor. This is true for both the laden and unladen condition. Consequently, the European trailer has less brake capacity than the North American semi-trailer (or the Australian semi-trailer).

Minimum trailer performance in FMVSS 121 (Table III) is shown with red dots. There is no upper limit to the trailer brake level in FMVSS 121. The Table III requirements do not apply to a truck-tractor.

Diagram 4A  
Semi-trailers  
(see paragraph 4. of this annex)



Note: The relation between the braking rate  $T_g/P_g$  and the control line pressure for the laden and unladen conditions is determined as follows:

The factors  $K_z$  (laden),  $K_v$  (unladen) are obtained by reference to diagram 4B. To determine the areas corresponding to the laden and unladen conditions, the values of the ordinates of the upper and lower limits of the hatched area in diagram 4A are multiplied by the factors  $K_z$  and  $K_v$  respectively.

**Diagram 4**

UN ECE Regulation 13 Adhesion Utilization (brake compatibility) limit diagram for a semi-trailer assuming  $K_c$  and  $K_v$  both equal 1.

The actual limits for a trailer may differ because  $K_c$  and  $K_v$  are to be calculated depending upon the trailer dimensions and weight ratings.

Minimum Brake Retardation Force limits for a trailer in FMVSS 121 (Table III) are shown by red dots.

## 4 Brake-Design Philosophy Differences

It might be thought that the same design approach would exist amongst brake system designers around the world because the physics of heavy vehicle braking is well known. This is not so. The main philosophical differences can be stated as follows:

**Nth American:** The ability to steer the motor vehicle during heavy braking is an over-riding requirement. The distribution of brake forces must not significantly reduce steering forces. Therefore, braking forces should be biased to the rear axles so that the wheels on the front axles can never lock-up. This bias should apply in both the fully-laden and lightly-laden states. This philosophy is more important than a 'balanced braking' philosophy.

Fitting relatively small brakes to the front axles requires the fitting of relatively powerful brakes at the rear axles in order to achieve an acceptable deceleration performance. Axle weight limits are significantly lower than in Europe.

For the combination vehicle, the trailer brake level should be substantial so that any tendency for jack-knife is reduced. This 'braking-from-the-rear' strategy is intended to keep the combination vehicle straight during heavy braking.

No particular adaptive brake technologies are necessary to implement the 'braking-from-the-rear' strategy.

**European:** Braking forces should be allocated according to the weight distribution on the axles. Otherwise, excessive braking from the rear will produce unstable vehicle dynamics. Therefore, wheels on the front axle should lock-up before the wheels on at least one rear axle. This requirement is 'enshrined' as a design-rule



specification (see below). The requirements apply to both the laden and unladen vehicle. Note axle weight limits are much higher than in the North America.

For the combination vehicle, compatible braking is desirable so that braking level should be reduced as the load is taken off. This ‘balanced braking strategy’ requires adaptive brake control technology.

The two different approaches that are described above continue to influence the design of intelligent brake control systems such as ESC. The history of the two approaches dates back to the 1970s.

An insight into the origins of the North American approach can still be found in state legislation. The following excerpt is from the British Columbia (Canada) brake regulations:

**Reduction of brake effort on front wheel permitted**

- 6.09** (1) Notwithstanding these regulations, means may be used for reducing the braking force applied to the front wheels of a bus, truck or truck tractor as compared to the braking force applied to the other wheels of the vehicle.
- (2) No person shall use or operate, or cause to be used or operated, any means for reducing the braking force applied to the front wheels of a vehicle as compared to the braking force applied to the other wheels of the vehicle, except when weather conditions make such use or operation essential to safety.

(Motor Vehicle Act Regulations – British Columbia, BC Reg 26 / 58, OC 1004 / 58, January 30, 2014)

The rationale behind this regulation is that when the roadway is slippery, lock-up of the front axle is unsafe. Manual controls that reduce the front-axle brake level are acceptable when the road is slippery. Antilock brake system has been mandated on new European trucks, buses and trailers since 1987. The European approach is to rely upon the Antilock brake protection to avoid steer-axle lock-up and subsequent understeer.

In 1975 the USA National Highway Transport Safety Administration (NHTSA) introduced the air-brake rule FMVSS 121 which included stopping distance requirements. By current standards the stopping distance requirements were modest. However, USA manufacturers struggled to meet the requirements because of the low steering-axle brake capability and hence the poor brake distribution balance. Antilock brake systems were developed to protect against wheel lock-up. These systems were not ready and proved to be unreliable. In a landmark decision (1978) in *PACCAR + ATA v NHTSA*, the Ninth Circuit Court of Appeals in California ruled against NHTSA and the stopping distance requirements in FMVSS 121 were dropped. This experience caused ABS development and sale to stop in the USA. It ultimately resulted in Europe taking a strong lead with the development of advanced braking systems.

## **5. Comparison of Features on European and North American Vehicles**

### **5.1 Service Brake Control Systems**

Diagram 5 (next page) shows a comparison of brake features that typically exist on North American and European trucks and trailers. It covers both the service brakes and the endurance brakes.

A further significant difference that cannot be shown in Diagram 5 is that European vehicles have air systems with average operating pressure of up to 10 bar (145 psi) whereas the average operating pressure on a North American vehicle is typically 100 psi. There is 45% more application pressure available on a European vehicle.



### Electronic Stability Control

Automatically applies individual wheel brakes to avoid crashing

Electronic Stability Control (ESC)

ESC incorporates RSS

European: ESC is mandated on truck-tractors. N America: Proposed rule FMVSS 136 will apply.

### Autonomous Vehicle Brakes

Automatically slows the vehicle to avoid crashing.

Roll Stability System (RSS)

Autonomous Emergency Braking (AEB)

Autonomous Cruise Control (ACC)

Trailers have RSS with EBD, which is called TEBS. Trucks have RSS as a feature of ESC. ACC is not mandated.

### Electronic Brake Control

Electrical transmission of brake control signals with pneumatic control circuit backup

Electronic Braking System (EBS)

EBS incorporates ABS and EBD.

European: EBS is the standard brake control system. EBS is rarely used in N America.

### Adaptive Brakes

Automatically changes the brake capability depending upon load to improve brake balance

Electronic Brake Distribution (EBD)

Load-Sensing Brakes (LSB)

European trucks have EBD coupled with ABS. N American trucks do not have Adaptive brakes.

### Antilock Wheel Protection

Alters the brake level at a wheel during braking to avoid wheel lock-up

Electronic Antilock Brakes (ABS)

Brake Modulation by the Driver

Antilock brakes are mandated on new trucks and trailers in European and N America.

### Trailer Brake Adjustments and Controls

Allows manual adjustment to improve the balance between a trailer and the towing vehicle.

Trailer Predominance Valves

Trailer Ratio Valves

Trailer Hand Control

Until the late 1990s European trucks commonly had Predominance Valves

N American trucks usually have trailer hand control and European trucks do not. N American trucks occasionally have trailer ratio valves.

### Endurance Brakes

Applies additional retardation to minimise foundation brake use.

Engine Brakes

Driveline Retarder Brakes

Engine brakes were predominantly used on N American trucks but is now common on European trucks.

### Foundation Brakes

Provides the braking action at each wheel end

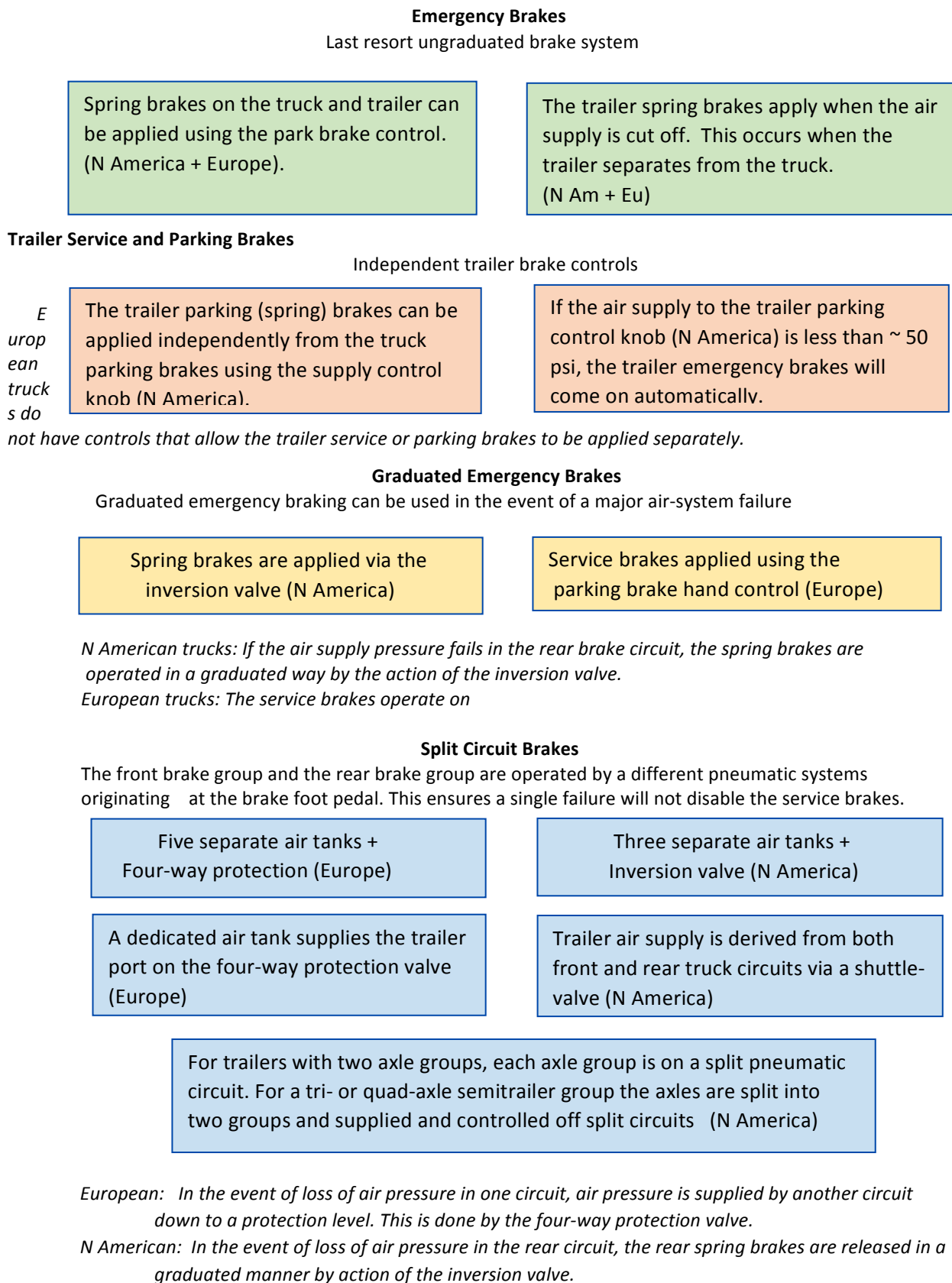
Drum Brakes

Disc Brakes

European vehicles usually have disc brakes. American vehicles usually have drum brakes.

## 5.2 Emergency Brake Control

Diagram 6 (below) shows a comparison of emergency brake controls and features that typically exist on North American and European trucks and trailers.



**Diagram 6 Emergency brake control system feature comparison**

## 6 Comparative Brake Testing

Comparative brake testing was conducted on a specially modified truck-tractor. Each of the two brake circuits was supplied off independently regulated air tanks with pressures that were set to produce the decelerations shown in Table 1. These characteristics are based upon the authors' interpretation of typical vehicle characteristics for North American and European truck-tractors and trailers. Tests were conducted on lightly-laden, half-laden and fully laden trailers with the loads and axle group weights shown in Table 2.

For each test set-up the combination vehicle was decelerated with sequentially increased brake level until the vehicle could no longer stop in a 3.7 m lane width on a 152.4m (500 ft) radius curve. The roadway was a continuously wetted, sealed asphalt with a tyre-road friction level (estimated) of 0.45.

Truck	Trailer	Laden	Half Laden (Even)	Half Laden Drive Heavy	Lightly Laden
ECE	ECE	0.273g E=0.6	0.246g E=0.55	0.260g E=0.5	0.217g E=0.4
ECE	N Am	0.214g E=0.4	0.259g E=0.55	0.162g E=0.25	0.156g E=0.2
ECE	LSB	0.214g E=0.4	0.242g E=0.5	0.202g E=0.35	0.161g E=0.25
N Am	ECE	0.223g E=0.45	0.246g E=0.5	0.254g E=0.48	0.221g E=0.3
N Am	LSB	0.260g E=0.5	0.256g E=0.5	0.248g E=0.45	0.245g E=0.3
N Am	N Am	0.260g E=0.5	0.246g E=0.4	0.185g E=0.3	0.244g E=0.3

**Table 1** Maximum stable average deceleration results, given in normalized (g) units.  
ECE = a vehicle with mid-band performance  
N Am = North American  
LSB = North American trailer with Load Sensing Brakes set to 65% when lightly laden.  
E is the applied control level. E =1 corresponds to 650 kPa.

Axle Group Loads	Unladen (t)	Half Load, Even (t)	Half Load, Drive Heavy (t)	Laden (t)
Truck tractor steer axle	4.90	5.19	5.47 / 5.8	5.51 / 5.9
Truck-tractor drive group	5.81	10.92	15.81 / 15.7	16.50
King Pin imposed load	2.70	8.10	13.27	13.99
Trailer tri-axle group	5.90	12.40	7.53	18.81
Load weight	0	11.90 at 4.66 m back from kingpin.  C of M height is 2.2m	12.20 at 1.14m back from kingpin.  C of M height is 1.8 m	24.22 at 4.55 m back from kingpin.  C of M of load is 2.25m
Total test vehicle weight	16.61	28.51	28.81	40.82

**Table 2** Axle-group weights.

Higher deceleration is advantageous. The lowest deceleration performance for any load condition is the benchmark for comparisons. The best overall performance is the North American truck-tractor pulling a North American trailer with *load-sensing brakes* set to 65% (unloaded). This produces slightly better performance, but comparable performance to the ECE truck-tractor pulling an ECE trailer. Both these combinations have *load-sensing brakes* on the trailer. The other combinations have significantly lower performance because the brake compatibility is poor for some lightly-laden or half-laden loading conditions. The important factor is the use of *load-sensing brakes* on the trailer. The European truck-tractor has *load-sensing brakes* whereas the North American truck-tractor does not however, this is not particularly important. The North American practice of biasing the brake power to the rear is advantageous but must be moderated by load-sensing brakes to protect against poor brake balance when lightly laden.

## 7. ESC Brake Testing

A second round of testing was conducted to investigate the performance of Electronic Stability Control (ESC) on a truck-tractor or trailer. During the second round of testing, a Volvo FH6x4 prime-mover was used that has an Electronic Braking System (EBS) with a stability control function. The trailer also had an EBS that incorporated a stability control function. When activated, the EBS incorporates electronic brake distribution (adaptive brakes) and stability control function (brake application on both vehicles to slow the vehicle when a pending roll-over is sensed).

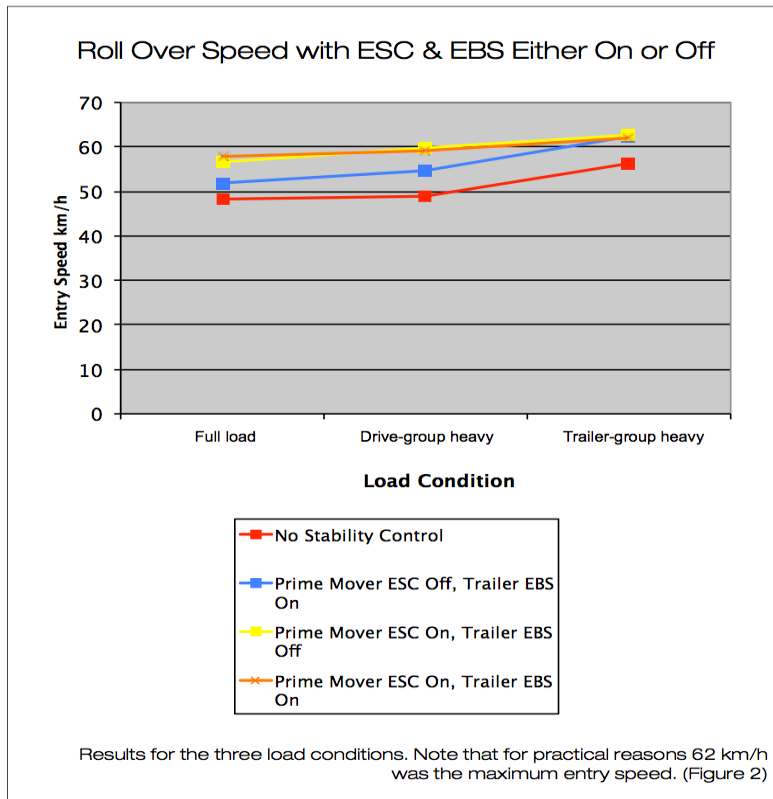
The trailer was fitted with outrigger wheels to prevent full roll-over. The combination vehicle was tested on a dry road. A series of tests was conducted for each load condition (Table 2). The combination vehicle was driven into a “j-curve” with a radius of 150 ft (46 m) on a 3.7 m lane width. The maximum entry speed was determined at which the combination vehicle could travel around the j-curve without rolling over.

Diagram 9 shows a summary of the results. The results show that higher entry speeds are possible when either the truck-tractor or the trailer have an active Electronic Stability Control (ESC). The performance with the only the truck-tractor ESC active is only slightly worse than with the ESC on both vehicle active. The truck-tractor ESC has three significant advantages which are:

- It measures the steering orientation and so the truck-tractor ESC gets information about the severity of the turn. This information is not available to the trailer ESC.
- The truck-tractor ESC assesses the severity of the turn much earlier than the trailer ESC can.
- The truck-tractor ESC system applies the service brakes on both vehicle parts. This slows the vehicle quickly.

The trailer ESC has the advantage that it can better assess the load level and the centre-of-mass height on the trailer because these measures can be estimated from side-to-side differences in the sensed trailer wheel speeds and the suspension airbag air pressures (for air-suspensions).

The results show that the advantages of the truck-tractor ESC system are substantial. The significance of this result is that mandating ESC on new truck-tractors but not on new trailers, as is proposed in North American (i.e. FMVSS 136), is likely to deliver most of the roll-over safety benefit that can be expected from mandating ESC on both new truck-tractors and new trailers, as has been done in Europe.



**Diagram 9** Results for the three load conditions. Note that for practical reasons 62 km/h was the maximum entry speed.

## 8. Conclusions

The distribution of brake capability on North American and European heavy vehicles is significantly different. North American vehicles tend to have powerful brakes at the rear and light brakes at steering axles. This approach is advantageous on laden vehicles because it tends to keep the combination vehicle straight. However, this approach is disadvantageous on unladen vehicles because vehicles easily become directional unstable. The best performance is achieved when the trailer has adaptive brakes. A suitable setting is 65% when unladen.

Most of the safety benefits from Electronic Stability Control (ESC) come from the truck-tractor unit and not from the trailer unit(s). This unit can make the earliest assessment of the safe cornering speed because it senses the steering wheel position, experiences the earliest yaw acceleration and can communicate directly with the engine. However, ESC on trailers is usually associated with an Electronic Brake Distribution function (EBD), which reduces the braking to a safer level when the trailer is unladen. Therefore it is unwise to only require ESC on the truck-tractor, as is proposed for FMVSS 136, because there will be no incentive to implement adaptive brakes on trailers. Both the truck-tractor and the trailer intelligent brake controls deliver different, complementary safety benefits.

## 9. References

UN ECE Regulation 13, *Uniform provisions concerning the approval of vehicles of categories M, N, O with respect to braking*. V7, 2013.

FMVSS 121, Air brake systems. Federal register 571.121.

FMVSS 136, Electronic Stability Control Systems on Heavy Vehicles, NHTSA, May 2012.