In-service assessment of agricultural trailer and trailed appliance braking system condition and performance

The Agricultural Trailer Braking Study

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The service and parking brake performance of a small but representative range of frontline agricultural trailers and trailed appliances from UK farms was quantified, to highlight possible inadequacies in trailer braking system specification and maintenance levels, particularly when used with faster (above 20 mph) tractors.

Braking performance was determined both in ‘As-Found’ off-farm condition and following maintenance. ‘As-Found’, 90% of test vehicles failed to meet UK statutory service brake performance requirements for vehicles travelling up to 20 mph, and 40% of parking brakes were inoperative. Following maintenance, 40% of vehicles achieved/exceeded the statutory service brake requirement and a further 20% approached the required performance level. Nonetheless, 40% of these modern and supposedly serviceable vehicles still failed to demonstrate adequate performance. Only one parking brake met the requirements stipulated by BS 4639:1987 and the proposed (draft) EU braking regulations for towed agricultural vehicles, either ‘As-Found’ or ‘Post-Maintenance’.

The requirements of existing and future UK and European agricultural vehicle braking legislation are reviewed. The vehicles tested are presented as case studies, considering the need for, and practical and economic feasibility of, upgrading their braking systems to permit safe (and legal) operation at 20, 25 and 30 mph maximum speeds. The construction and operation of agricultural trailer braking systems are reviewed and recommendations made regarding selection for typical UK agricultural applications.

Future EU tractor-trailer braking legislation is likely to require significantly greater performance. This can be achieved without undue difficulty or excessive cost, but there is a vital need to raise user awareness and understanding of trailer and trailed appliance braking system specification and selection, to minimise future performance shortfalls.

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EXECUTIVE SUMMARY

An efficient vehicle braking system is essential for safety during transport operations, but general opinion suggests that agricultural trailer (and trailed appliance) braking systems are often given insufficient consideration, both at the time of purchase and during subsequent use. In many instances, braking system specification and degree of in-service maintenance is suspected to be inadequate for safe use behind modern ‘conventional’ tractors, whose maximum road speed is usually 25 mph (40 km/h) and often 30 mph (50 mph). The majority of UK trailer braking systems are designed to meet statutory requirements for use at 20 mph (32 km/h) maximum speed. Stopping a tractor-trailer combination from 30 mph requires the braking system to dissipate 144% more energy (approximately 2.5 times) than would be experienced from an initial speed of 20 mph. Whilst modern tractors have been designed to cope with this increase, if the trailer’s braking system has not, the excess braking load is transferred to the tractor’s system, resulting in overloading, rapid wear, premature failure and a costly repair bill.

This investigation has sought to quantify and raise awareness of this (increasing) problem, and identify practical, cost effective solutions. Sponsored jointly by the Health & Safety Executive, the Department for Transport and a consortium of six tractor manufacturers (AGCO, CNH, Claas, JCB, John Deere and McCormick) via the Agricultural Engineers Association (AEA), the primary aim of this study was to generate information to raise user (and prospective purchaser) awareness regarding the inadequate performance of many agricultural trailer braking systems currently in-service, and the options available to rectify the situation, both in terms of practicality and economic viability. It is hoped this will in turn lead to safer vehicle operation and assist compliance with future agricultural trailer and trailed appliance braking legislation.

The braking performance of a small but representative range of typical in-service frontline agricultural trailers and trailed appliances (e.g. slurry tankers, big balers), sourced directly from East Anglian farms, was investigated to determine:-

- Vehicle braking performance ‘As-Found’ and following braking system maintenance;
- The ability of the selected agricultural vehicles to comply with existing and/or forthcoming braking system legislative performance requirements;
- The nature, cost and feasibility of any modifications required to achieve legislative compliance and/or permit safe, cost-effective vehicle operation.

The findings of the investigation may be conveniently categorised into the following distinct but nonetheless related areas:-

i) In-service performance of trailer (and trailed appliance) braking systems;

ii) Choosing and using agricultural trailer brakes:-
   a) Maintaining and/or upgrading existing vehicle braking systems
   b) Selection of appropriate systems on new vehicles

iii) Agricultural trailer braking legislation.

(Continued)
In-Service Trailer Braking System Performance

Assuming the trailers and trailed appliances targeted are representative of (hydraulically-braked) vehicles in frontline service on UK farms, it would appear that more than 80% of such vehicles are being operated with inadequate (and illegal) service braking systems. Such shortfalls in towed vehicle braking performance greatly increase the braking load imposed upon the towing vehicle (tractor) and significantly increasing the likelihood of excessive tractor brake wear and premature system failure.

In ‘As-Found’ off-farm condition, 90% of the trailers / trailed appliances tested failed to meet the current UK statutory service brake performance requirement (minimum 25% efficiency) for 20 mph (maximum speed) operation. Following farm workshop maintenance, 40% of the vehicles achieved / exceeded the statutory requirement and a further 20% approached the required level, but 40% of these modern and supposedly serviceable vehicles still failed to demonstrate adequate service brake performance. The parking brakes of 40% of the test vehicles were inoperative in ‘As-Found’ off-farm condition. Only one vehicle met the parking brake performance requirements stipulated by BS4639:1987 and the proposed (draft) EU Regulations for towed agricultural vehicles, either ‘As-Found’ or ‘Post-Maintenance’.

Inadequate maintenance was undoubtedly the primary cause of poor vehicle braking system performance in ‘As-Found’ condition. However, this was primarily due to lack of brake actuation system adjustment, rather than failure to renew worn-out components (e.g. friction linings). It is not possible to determine whether maintenance shortfalls resulted from lack of appropriate knowledge or failure to implement adequate procedures. Additionally, the ‘Post-Maintenance’ service brake performance results suggest that, in certain instances, shortfalls in vehicle braking system design and/or specification prevented compliance with UK statutory (Construction and Use) requirements.

Choosing and Using Agricultural Trailer Brakes

To prevent overloading of the tractor’s braking system, it is extremely important that the braking performance (efficiency) of a trailer / trailed appliance is similar or equal to that of the towing vehicle (typically 45 – 60%). Modern trailers must therefore achieve significantly greater braking performance than the current UK minimum 25% efficiency level for 20 mph operation. Otherwise shortfalls in the trailer’s braking performance must be made up for by the tractor’s brakes, with inevitable results. Tractor-trailer stability during braking will also be compromised. This has possibly not been an issue at slower road speeds, but tractor maximum speeds in excess of 20 mph have been commonplace now in the UK for over a decade.

Single-line hydraulically-actuated trailer brakes have served UK agriculture well for the last 30 years, but trailer / trailed equipment size and ‘conventional’ tractor maximum road speeds are such that a more comprehensive, higher performance system is now required. It is possible to upgrade hydraulic trailer brakes to deliver acceptable performance and response characteristics (including breakaway failsafe functionality). Alternatively, consideration should be given to appropriate dual-line pneumatic braking systems. In any case, it is essential that a trailer’s / trailed appliance’s foundation brakes are large enough to meet the energy dissipation requirements induced by vehicle payload and, more significantly, likely maximum operating speed. The braking system loading when stopping from 30 mph (50 km/h) is approximately 2.5 times that resulting from an initial speed of 20 mph. Also, ‘S’ cam-type foundation brakes are preferable to the ‘flat’ cam type, for operation at speeds above 20 mph.

The braking performance of in-service (tandem-axle) trailers can frequently be improved at relatively limited (component) cost: typically £700 – £1300 if the existing axles and foundation brakes are suitable for the intended purpose, rising to ~£2500 if replacement axles and larger (‘S’ cam-type) foundation brakes are also required. The running and replacement component costs of larger (commercial) specification axles and brakes are frequently much lower than
those of smaller, agricultural specification units, due to component commonality with other on-road vehicles.

If contemplating purchase of a new vehicle, or upgrading an existing trailer / trailed appliance, the braking system specification and design should be selected to assist and encourage regular brake adjustment and servicing, e.g. fitment of brake lever arms incorporating manual, screw-type slack adjusters. Spending a few tens of pounds can really make the difference between a system being adjusted (and working) or not! Remember a new trailer will probably outlast 2 – 3 replacement tractors (15 – 25 years plus), so it is important to invest for the future. Additionally, if equipped with a higher-specification (~50% efficiency) braking system, as required for above-20 mph operation in the UK, it is essential the trailer incorporates a load sensing system to avoid over-braking, wheel lock, excessive tyre wear and potential vehicle instability during unladen braking. Anti-lock (ABS) brakes are also currently a UK statutory requirement for trailers used above 20 mph.

In many instances the braking performance of in-service hydraulically-braked trailers and trailed appliances may be improved by increasing brake ram diameter (actuating force). However, this is not a step to be taken by the uninformed, particularly without the advice of the trailer manufacturer and/or the axle supplier. If system performance is improved by this method, the addition of a load sensing system will probably be necessary to prevent over-braking when unladen. Finally, it is a UK legal requirement that towed agricultural vehicles used at speeds above 20 mph incorporate a breakaway failsafe braking system to apply the trailer brakes upon accidental tractor-trailer separation. Retrofit electro-hydraulic failsafe systems are available for existing (single-line) hydraulically-braked vehicles, whereas dual-line pneumatic braking systems already incorporate this function. Given that virtually every tractor > 80 hp sold in the UK since 1995 is capable of 25 mph (40 km/h) road speed, it is perhaps surprising that breakaway failsafe trailer braking systems are not more commonplace.

Agricultural Trailer / Trailed Appliance Braking Legislation

At present, agricultural trailer braking regulations in the UK are arguably outdated. There is no official means of ensuring agricultural trailer braking systems are legally compliant when first sold. Once in-service, a statutory responsibility is placed upon the user to ensure the towed vehicle’s braking system is maintained and continues to perform adequately, albeit there is at present no convenient, recognised and readily-accessible means of quantifying levels of trailer braking system performance. The proposed EU agricultural vehicle braking regulations will potentially serve to remove confusion regarding tractor-trailer braking, by stating clear, enhanced system performance requirements. Whilst necessitating greater braking performance, which arguably should have already been present on existing agricultural trailers used above 20 mph, for UK regulatory compliance, the industry will benefit from the reduction in (or hopeful elimination of) the disparity between tractor and trailer braking performance requirements. In practise this is likely to improve vehicle combination braking and stability, enhance safety and almost certainly reduce tractor-trailer braking system repair costs.

It is strongly-advised that current UK statutory braking performance requirements for agricultural vehicles be clarified / modified to specify:-

• The actual system actuating (line) pressure at which the stipulated (minimum) levels of service brake performance should be achieved, thereby avoiding possible confusion and ‘interpretation’;

• An actual minimum value for agricultural trailer and trailed appliance parking brake performance.
It is also suggested that, either by introduction of a statutory requirement or an industry code of practice, information regarding the need for, frequency and means of brake adjustment should be clearly displayed on the vehicle chassis / body.

**Possible Future Work**

Subject to resource availability, it is considered the following issues would benefit from further investigation in the near-future, particularly given the forthcoming introduction of EU tractor-trailer braking regulations, EC Type-Approval for agricultural trailers and trailed appliances, and the inevitably increasing proportion of the UK tractor fleet which will have 30 mph (50 km/h) maximum road speed capability. Many questions as yet remain unanswered, including:-

- The adequacy of performance of (pneumatic and/or hydraulic) load sensing braking systems on agricultural trailers and the steps necessary to redress any possible shortfalls;

- The response characteristics of hydraulic trailer braking systems. Can they meet the performance levels likely to be stipulated by EU tractor-trailer braking regulations? What modifications would be necessary to enable existing system designs to do so?

- Hydraulic trailer braking systems are still permitted by the EU regulations, albeit in enhanced format. Can hydraulic trailer braking systems meet these requirements and, if so, in what form? If not, is it appropriate to encourage a wholesale conversion to pneumatic trailer braking systems in the UK?
1. INTRODUCTION AND INVESTIGATION OBJECTIVES

An efficient vehicle braking system is central to safety during transport operations, be they on or off-road, but agricultural trailer (and trailed appliance) braking systems are frequently given insufficient consideration, both at the time of purchase and during subsequent use: their initial specification and subsequent level of in-service maintenance frequently now proving to be inadequate for safe use behind modern ‘conventional’ tractors.

Most UK agricultural trailers are fitted with braking systems designed to operate within the 20 mph (32 km/h) UK maximum speed limit for slower agricultural vehicles, as specified by the Road Vehicles (Construction and Use) Regulations (Statutory Instruments, 1986). However, virtually all UK tractors sold since 1995 have 25 mph (40 km/h) max. speed capability and many modern ‘conventional’ tractors are now capable of 30 mph (50 km/h) on-road. Whilst use of agricultural tractors and trailers on UK roads at speeds above 20 mph is illegal without commercial vehicle-specification braking performance (including ABS) and full suspension (in the case of the tractor), in practice it is frequently viewed as a preferable alternative to increased frustration and recklessness on the part of other road users, as a consequence of experiencing excessive delays behind slow-moving agricultural vehicles.

Tractor-trailer operation at 30 mph increases the energy dissipation requirement placed upon the vehicle braking systems by over 140% (an approx. 2.5 times increase) (see Figure 1.1). Whilst modern tractor brake systems have usually been engineered to accommodate this increase, trailer braking systems currently in-service frequently have not: a situation accentuated by the fact that agricultural trailers are usually expected to have a frontline service life of 15 - 20 years plus. A trailer can easily outlive two or more generations of tractor, but only if the running gear and braking systems are adequately specified in the first instance. If the trailer braking system is undersized, the initial consequence is accelerated wear and premature failure of the trailer braking system, followed by overloading, rapid wear and eventual failure of tractor braking system. This has become an increasing problem within the UK and Eire in recent years, as demonstrated by the proportion of tractor braking system failures during vehicle warranty periods arising from these regions.

In addition to current ‘in-service’ issues, forthcoming EU tractor-trailer braking legislation (EEC, 2007) will demand higher performance from new tractor and trailer braking systems, although in practice the degree of improvement required of trailer systems will be far greater than those of the tractor, as the latter already frequently meet the new requirements. However, improving tractor braking performance, in response to higher road speeds and in anticipation of future legislation, has in fact served to increase the disparity between tractor and trailer braking system performance, causing further overloading the towing vehicle’s system.

So what can be done to remedy the situation? In reality the proposed trailer braking performance targets are achievable, given selection and installation of appropriately-sized equipment. However, unless the braking systems of existing ‘in-service’ agricultural trailers are reviewed and (if necessary) upgraded, a major safety risk will result from the performance disparity between ‘new’ tractors and ‘older’ trailers, given that the majority of the braking effort will originate from the towing vehicle.

This investigation has sought to quantify the extent of this problem in the UK at present and identify practical, cost-effective measures that may be implemented, ideally on-farm or by local engineers, to address it. Surely better to select an appropriate specification trailer when renewing, or re-condition an existing trailer at relatively modest cost by fitting suitable running gear and appropriately-sized brakes, rather than have to replace oil-immersed tractor

1
brakes at up to £2000 plus per instance? If buying a new trailer, how can braking system specification affect not only braking performance, but subsequent service intervals and running costs? Can it actually make good economic sense to upgrade the braking systems of older trailers which remain in regular use, particularly if operated behind modern 30 mph / 50 km/h ‘semi-suspended’ tractors or is it cheaper (and safer) to buy a new machine? Are some trailer designs more suitable for upgrading than others? What components are likely to be required and from where may they be sourced?

Information regarding these important, safety-related issues is not readily available. To address the matter, this investigation, sponsored jointly by the Health & Safety Executive, the Department for Transport and a consortium of six tractor manufacturers (AGCO, CNH, Claas, JCB, John Deere & McCormick) via the Agricultural Engineers Association (AEA), has sought to quantify the extent of this problem in the UK at present and highlight the relative attractiveness and practically of the various options available to address it.

![Image](image.png)

**Figure 1.1** Disproportionate effect of increasing speed upon vehicle kinetic energy

Rather than generate data to potentially-penalise tractor-trailer transport activities in the UK, the primary aim of this investigation was to produce information to underpin an HSE / DfT / Industry publicity campaign to raise user (and prospective purchaser) awareness of the inadequate performance of many agricultural trailer braking systems currently in-service, and the practical means and economic viability of rectifying the situation. This should in turn lead to safer operation and assist compliance with future agricultural trailer and trailed appliance braking legislation, particular issues being:-

- the disparity between current tractor and trailer braking system performance;
- the economic and safety benefits of selecting adequate braking systems when purchasing new trailers and trailed appliances;
- the scope for (and economic benefits of) voluntarily upgrading existing trailer / trailed appliance braking systems to meet the requirements of forthcoming EU legislation;
- the need for regular maintenance of agricultural trailer braking systems.
With this background in mind, the specific objectives of this investigation were therefore to investigate the braking performance of a small but representative range of typical agricultural trailers and trailed appliances (e.g. slurry tankers, big balers), to:-

i) Determine levels of vehicle braking system performance:-
   a) in ‘as-found’ on-farm condition;
   b) following typical ‘on-farm’ maintenance and fault rectification.

ii) Ascertaining the ability of the selected vehicles to comply with future agricultural trailer braking system performance requirements and predict braking system performance and service life if operated frequently with modern (40–50 km/h) ‘conventional’ tractors;

iii) Determine the nature, cost and economic feasibility of any modifications necessary to enable the selected trailers and trailed appliances to comply with forthcoming agricultural vehicle braking legislation.
2. AGRICULTURAL TRAILER BRAKING HARDWARE

2.1 INTRODUCTION

Agricultural trailer braking systems are usually classified according to their actuation medium, i.e. ‘pneumatic’ or ‘hydraulic’ but, as can be imagined, this is only part of the story. Many other components in addition to the actuation system contribute to overall braking system performance. Because of their almost universal use upon commercial and higher-speed (> 20 mph) agricultural vehicles, pneumatic braking systems are often considered superior to their hydraulic counterparts. However, even though (for example) a trailer may be fitted with dual-line, failsafe pneumatic brakes, if the brake drums and shoes are undersized or worn, or if the system is poorly adjusted, the amount of braking effort generated will be significantly compromised: ..... air brakes or no air brakes! So always consider the specification (and the condition) of the entire package: there are no shortcuts.

During brake operation (see Figure 2.1), force generated by the (hydraulic) brake ram or (pneumatic) brake chamber (1) is transferred to the brake lever arm / slack adjuster (2) and thence to the camshaft (3) and brake operating cam (4). Cam rotation forces the brake shoes (5) apart and against the inside of the brake drum (6), resisting wheel / hub rotation. The friction generated between the brake shoe lining and the brake drum causes vehicle kinetic energy to be converted into heat, which in turn is transferred to, and dissipated to the atmosphere by, the brake drum.

Figure 2.1 Typical trailer axle and drum brake assembly (courtesy BPW Ltd)
(1) pneumatic brake actuator, (2) brake lever arm – featuring slack adjuster, (3) camshaft, (4) S-type brake operating cam, (5) brake shoe, (6) brake drum
The braking effort generated by a trailer / trailed appliance axle is dependent upon:

i) Brake drum size \((\text{drum diameter and shoe width})\)

ii) Brake operating cam characteristics

iii) Brake lever arm operating radius \((\text{actuator attachment point})\)

iv) Brake ram / chamber internal diameter

v) Brake line pressure

vi) No. of brake rams / chambers per axle \((\text{one per axle-end or one per axle})\)

vii) Tyre static loaded radius

However, vehicle total braking effort also depends upon the number of braked axles fitted to the trailer and is ultimately limited by tyre-surface adhesion.

2.2 FOUNDATION BRAKE

Apart from the actual brake drums and shoes, a number of other components influence the ultimate performance of a vehicle braking system (see Figure 2.1). In addition to the camshaft, the lever arm and the (hydraulic or pneumatic) brake actuator, an entire pressure control system is also required. When faced with such an extensive system, it is common industry practice to refer to the actual end-of-line braking components (i.e. the brake drum, shoes and operating cam or the disc & pads) as the ‘foundation brake’, to which other components are added to create the braking system. At present conventional axle-mounted drum brakes enjoy dominance of the agricultural trailer / trailed appliance market. Disc brakes have entered the heavy truck market, but the performance and low running costs of drum brakes seems likely to ensure their continued presence for the foreseeable future.

The foundation brake is required to dissipate vehicle kinetic energy as heat over a long service life without incident. Selection criteria include brake force / torque capacity, and resistance to wear (likely service life) and fade (due to overheating). Foundation brake size must be selected to suit the levels of energy likely to be dissipated on the vehicle, the latter being a function of vehicle mass (i.e. axle load) and likely maximum operating speed.

\[
\text{Vehicle Kinetic Energy} = \frac{1}{2} m v^2
\]

\(\begin{align*}
\text{where:} & \\
& m = \text{vehicle mass (kg)} \\
& v = \text{vehicle speed (m/s)}
\end{align*}\)

However, as shown by Equation 1 and Figure 1.1, increasing vehicle speed disproportionately increases the amount of energy which the braking system has to dissipate. Consequently its extremely important that a trailer’s foundation brakes are sized to suit the energy levels they are likely to handle, particularly if higher-speed use is a possibility in the future. If undersized, ultimate braking performance will always be compromised and overheating and rapid friction lining wear will result. However, if the foundation brakes are oversized, progressive brake control will be difficult and the trailer will be over-braked when unladen, resulting in wheel locking, excessive tyre wear and possible instability. Additional components (e.g. load sensing valves or ABS) may be included in the braking system to overcome such difficulties, but it is essential to select the correct capacity foundation brake in the first instance and then match it with an appropriately-sized brake actuator and lever arm, to achieve the levels of braking effort required by the vehicle.
Drum brakes are defined in terms of the drum diameter and brake shoe width (e.g. Ø 300 x 60, Ø 400 x 80, Ø 420 x 180 – see Figure 2.2) and the type of operating cam employed (e.g. flat or S-type). Flat-type cams have historically been the standard choice for (supposedly) slow-speed agricultural vehicles which do not exceed 20 – 25 mph (32 – 40 km/h). Brakes designed for higher speed / higher capacity (commercial vehicle) use feature S-type cams, which provide much more progressive control of braking effort than their flat-type counterparts: they are therefore by far the better choice for higher axle load and higher speed applications. Indeed, the majority of axle manufacturers would recommend ‘S’ cam brakes for agricultural use at speeds above 25 mph / 40 km/h and this trend is now reflected in the specifications of most high capacity (> 14 tonne) trailers sold in the UK.

Two interrelated factors influence choice of foundation brake size, namely the braking effort (or torque) required and the likely duty cycle. In simplistic terms these may be considered as ‘What has to be stopped?’, ‘How rapidly?’ and ‘How often?’. For a given operating cam torque, the developed braking torque is a function of drum / shoe diameter and friction lining width. However, the energy dissipation rate of a drum brake is dependent upon the drum size and surface area. Unless the latter is sufficiently high to accommodate the energy absorption rate of the brake assembly under the particular duty cycle in question, the brake drum and shoes will overheat. This causes a condition known as brake fade, which drastically reduces the braking effort that can be generated for a given input force, whilst simultaneously causing accelerated friction lining wear. So brake drums must be large enough to dissipate the heat!
However, whilst brakes need to be large enough, installation of oversized foundation brakes can also cause problems. Reduction of brake shoe – drum contact pressure levels to avoid characteristic over-braking can cause insufficient lining wear, resulting in ‘glazing’ of the friction linings and a substantial reduction in potential braking effort. Big brakes are not necessarily the universal solution! It is important to use the correct size of foundation brakes on a given vehicle, but it is also equally important to select the other braking system components to produce the desired vehicle braking characteristics and appropriate service life.

2.3 BRAKE LEVER ARM / SLACK ADJUSTER

A simple component, but it plays a vital role which is often overlooked. Not only does the lever arm convert brake actuator force into camshaft torque to operate the foundation brake (see Figure 2.1); for most agricultural and commercial trailer brakes it also provides the main means of free-travel adjustment to accommodate system / friction lining wear. Three types of brake lever arm are commonly found on agricultural trailer braking systems. All feature alternative mounting holes for the brake actuator connecting rod, to help the trailer designer achieve appropriate camshaft torque levels from a given brake ram, to suit the vehicle’s braking requirements. Their main distinguishing feature is the relative ease with which excess system travel may be adjusted:-

• **Simple, splined attachment (see Figure 2.3):** Currently the most common system found on agricultural trailers. Retained on the splined end of camshaft by a pinch bolt or circlip. Brake adjustment necessitates removal of the lever arm and relocation in an alternative angular position on the camshaft. Process frequently requires removal of the brake ram from the lever arm and often will only provide a coarse level of adjustment. Largely confined to hydraulic trailer braking systems;

• **Manual slack adjuster (see Figure 2.4):** Once the standard adjustment system on commercial vehicle axles; now frequently found on better quality agricultural trailers. Incorporates a internal worm gear and wheel. Turning an external nut gradually rotates the lever arm around the camshaft. No system disassembly required: adjustment is simple, quick, and convenient;

• **Automatic slack adjuster (see Figures 2.5 & 2.6):** Now state-of-the-art for commercial vehicle drum brake installations. Effectively a modified manual slack adjuster incorporating an automatic ratchet system on the adjusting worm gear. When excess travel occurs upon brake application, the ratchet assembly turns the worm and takes up a proportion of the travel as the brake is released. Requires no manual intervention other than 6 – 12-monthly lubrication and checking.

The timely adjustment of excess system / brake actuator travel (‘slack’) is very important if trailer braking performance is to be maintained. Most brake actuators, be they hydraulic rams or pneumatic diaphragm chambers, have a working stroke of approx. 75 mm / 3 inches. A drum brake requires a certain finite shoe – drum clearance to prevent dragging when the brake is released (see Figure 2.6). This clearance consumes a certain proportion of the brake actuator stroke, as does system elasticity (H & E in Figure 2.6). Further actuator movement then creates braking effort proper, but during normal service friction lining wear increases the initial brake clearance, progressively reducing the actuator stroke available to perform braking. Eventually the brake ram / chamber will reach its internal end stop and, without adjustment, the force applied to the lever arm, camshaft, brake shoes and the resultant braking effort, will diminish dramatically. Trailer manufacturers recommend that, with the brakes fully-applied, actuator travel should not exceed ⅔ of maximum, i.e. ~50 mm. The presence of any greater travel should be addressed immediately by adjustment of the brake lever arm and/or actuator mounting point.
Figure 2.3  Simple, splined brake lever arms (left) and attachment to camshaft (right)

Figure 2.4  Lever arm featuring manual slack adjuster (left) and adjustment (right)

Figure 2.5  Brake lever arm featuring automatic slack adjuster (courtesy BPW Ltd)
Braking system performance is also affected by the efficiency of force transfer from the brake actuator to the brake shoes. The angular relationship of the actuator and brake lever arm can have a significant effect upon this. Ideally the lever arm should be positioned on the camshaft so that the brake actuator and lever arm are perpendicular to each other when the brakes are fully applied, thereby maximising the camshaft torque generated (see Figure 2.7). If the included angle is allowed to depart from 90° (e.g. due to poor system design or failure to adjust excess system travel), braking effort will diminish disproportionately. Certain actuator / lever arm installations may not permit this ideal angular position, in which case the system designer must make allowance for the likely reduction in performance.

Most axles support the brake camshaft at two points: as it passes through the drum backplate and also close to the lever arm. Commercial vehicle and higher capacity axles tend to utilise plain or proprietary shell bearings, but provide grease nipples for their lubrication. However, the bearings used by the inherently-simpler agricultural trailer axles rarely provide means for lubrication and the support bearing adjacent to the lever arm is often simply a hole in a steel plate. With a narrow bearing surface and no provision for lubrication, the support plate / camshaft interface can be prone to wear and also a source of friction. The former increases the system free travel, whereas the latter reduces the proportion of actuator force reaching the brake shoes: neither scenario being conducive to good system performance.
2.4 TRAILER BRAKE ACTUATION / CONTROL SYSTEMS

In vehicular terminology, the service brake is that brake normally applied by the driver (or assistant) to decelerate the moving vehicle. In theory a trailer (or trailed appliance) service brake could be applied either:

i) solely by human effort;
ii) by the overrun / inertia force of the trailer acting towards the towing vehicle;
iii) by the controlled action of external power source (e.g. hydraulic or pneumatic pressure).

Tractor-trailer braking research studies conducted by the NIAE in the late-1960s (Dwyer, 1970) concluded that both overrun and power-applied trailer brakes could provide very useful improvements in overall braking performance, but power-applied brakes were preferred due to the difficulty of fitting effective overrun brakes to unbalanced (weight-transfer) trailers common in the UK. The research also considered the tractor’s external hydraulics to be the most convenient source of power for trailer brake operation.

Power-applied tractor-trailer braking systems were not unknown in the early-1970s: indeed in France they were a legal requirement upon agricultural trailers and trailed implements which exceeded 6 tonnes laden weight (Kittle & Hille, 1974). However at this time, most UK-built trailers relied on manually operated braking systems to meet legal requirements (Bull, 1982); a hand lever connected to the trailer brakes being provided within (supposedly) convenient reach of the driver’s seat. Mandatory UK introduction of quiet (Q) cabs on new tractors built after June 1976, effectively enclosed the driver and isolated him from the (frequently-ignored) trailer brake lever. The introduction of one piece of tractor-related legislation (in-cab noise levels) therefore hampered widespread compliance with another (trailer braking) and
potentially reduced vehicle safety. This together with increasing tractor and trailer size necessitated a rapid solution be found to the tractor-trailer braking problem: one which would gain widespread industry acceptance and result in rapid implementation by tractor and trailer manufacturers alike.

Given the likely lead-time of any revision to UK road vehicle legislation, an industry guidance code – ‘Agricultural Trailer Braking Systems’ - was developed (HSE, 1979) by the Department for Transport, in conjunction with the HSE, MAFF, DoI, AEA, NFU, NIAE and BAGMA, its purpose being to improve the braking of trailed agricultural vehicles. Whilst having no legal standing in its own right, the abovementioned Government departments and industry bodies recommended the code be adopted by “all who manufacture or use agricultural trailers”. The code made recommendations concerning the design and performance of trailer braking systems, the majority of which were formalised in BS 4639:1987 (BSI, 1987) and a 1984 amendment to UK (Construction and Use) Regulations (Statutory Instruments, 1984). However, the code went further insomuch as it also strongly advocated the adoption of single-line, power-applied hydraulic trailer brakes, for reasons of the minimal degree of tractor modification and additional equipment required, thereby encouraging rapid implementation by manufacturers and users. It also noted that the single-line hydraulic trailer braking system was well-proven and component parts were readily available. However, it must be remembered that this braking system was only deemed suitable for conventional (not ‘fast’) agricultural vehicles operating up to 20 mph (32 km/h) maximum speed.

Consequently, since the early-1980’s power-applied braking systems have become standard equipment upon virtually all but the smallest agricultural trailers sold in the UK, and these rely either upon hydraulic or pneumatic power for operation. The recommendations of the agricultural trailer braking code have resulted in single-line hydraulic systems (see Section 2.4.1) becoming by far the most prevalent, particularly as UK road vehicle legislation precluded the use of overrun brakes on agricultural trailers of greater than 3.5 tonnes laden weight and pneumatic braking systems were generally more complex and costly to install. However, whilst current single-line hydraulic systems provide a simpler, cheaper and (potentially) lower-performance configuration compared with (truck-derived) pneumatic braking systems, it is worth remembering that, technically, there is no reason why a hydraulic trailer braking system cannot be constructed to achieve performance levels similar to those of a pneumatic system. It is simply a matter of component availability, system complexity and overall cost.

2.4.1 Hydraulic Trailer Brake Actuation / Control

The standard method of hydraulic braking currently used on agricultural trailers in the UK is a single-line, ‘power-on’ pressure-modulated system, which derives its power from the tractor’s internal hydraulic system. Most modern tractors (less than 15 years old) supply hydraulic pressure to a dedicated (ISO 5676-compliant) coupling mounted at the rear of the cab. Pressure supplied to the coupling varies in direct proportion to tractor brake pedal effort (zero to 135 – 150 bar max.). A single trailer-mounted hydraulic pipe leads to simple, single-acting brake rams (see Figure 2.10) mounted upon the trailer axles, which operate the brakes by means of lever arms and camshafts (see Figures 2.1 & 2.4). System return springs ensure ram retraction when the tractor brake pedal is released and system pressure drops to zero. The brake actuating force generated by the rams is dependent upon system pressure and ram diameter, Ø20 and Ø25 mm being common but Ø30 and Ø35 mm being readily available. The UK agricultural trailer braking code (HSE, 1979) and BS 4639 (BSI, 1987) both stipulate 100 bar (~1500 psi) as a baseline standard for system performance assessment. Figure 2.8 shows the dramatic effect apparently small changes in brake ram diameter have upon the actuating force generated. Brake ram stroke is usually a maximum of 75 mm (~ 3 inches).
14000
12000
10000
8000
6000
4000
2000
0
Ø20 Ø25 / T12 Ø30 / T16 T20 Ø35 / T24 Ø40 / T30

Brake Actuator Thrust (Newtons)
@ 100 bar hydraulic / 6.5 bar air pressure

Figure 2.8 Effect of brake actuator diameter / size upon actuating force generated
(data courtesy GES Hydraulics Ltd)

**Hydraulic Braking**

**System Advantages:**

i) Simple: easy to understand and operate;

ii) Uses power source already available on tractor;

iii) Requires minimum of modification to tractor;

iv) Cheap / cost effective.

**System Disadvantages:**

i) Prone to contamination:- oil attracts dirt;

ii) Not failsafe: no stored energy source on trailer: no braking if it de-couples or the tractor’s hydraulics fail;

iii) System performance dependent upon tractor brake valve / oil supply characteristics;

iv) System response dependent upon oil flow from tractor to trailer: potentially restricted by pipework diameter.

So, given the abovementioned limitations, why are we using single-line hydraulic trailer brakes? The simple answer is that, back in the late-1970’s, UK government and the agricultural industry recognised the potential benefits of the widespread adoption of power-applied brakes upon agricultural trailers, but also accepted that a sensible balance had to be drawn between system complexity, performance and cost, in order not to limit rapid and broad system uptake or impose an unfair economic burden on the industry. Very few tractors were fitted with air compressors and the cost of installing pneumatic braking systems was significant. Every tractor had a hydraulic system: single-line hydraulic braking systems represented a massive improvement over much of what was then in use and offered the best prospects of old : new tractor-trailer compatibility. Also, very few tractors on sale at that time were capable of exceeding the (present) maximum speed limit of 20 mph (32 km/h) for conventional, unsuspended agricultural vehicles. This is no longer the case, with the consequence that many (20 mph-rated) hydraulic braking systems are now being expected to operate beyond their capability. Nonetheless, it is technically possible for a correctly designed and installed hydraulic system to generate appropriate levels of trailer braking performance (Dodd et al., 2007).
Figure 2.9 Dual-line, load sensing pneumatic braking system for a tandem-axle trailer (courtesy WABCO)

2.4.2 Pneumatic Trailer Brake Actuation / Control

Agricultural trailer pneumatic (air) braking systems use technology well-proven in on-road vehicle applications. However, it would be incorrect to believe that the systems are identical to those used upon large goods vehicles (LGVs). Technically, air brakes can be of single, dual or three-line configuration: LGVs frequently use three-line systems whereas pneumatically-braked agricultural trailers and trailed appliances usually employ a dual-line system as shown in Figure 2.9. The fundamental feature of any (pneumatic or hydraulic) dual-line braking system is that energy is stored on the trailer, in a suitable reservoir. In the case of dual-line air brakes, this reservoir is filled and maintained at system operating pressure (~8 bar) via the red ‘supply’ line from a compressor and reservoir on the towing vehicle.

Unlike a single-line system, the supply line pressure does not vary with braking effort. Braking action is controlled by a ‘relay-emergency’ valve mounted upon the trailer, which directs air pressure from the reservoir / supply line to axle-mounted brake actuators (air chamber incorporating a diaphragm and return spring). The relay valve (and hence the trailer braking effort) is controlled by a separate air supply from the towing vehicle, routed via the yellow ‘control’ line, the pressure of which varies in direct proportion to tractor brake pedal effort. This in turn varies the pressure supplied by the relay-emergency valve to the brake actuators (from zero to 8 - 8.5 bar max.). Braking system performance is assessed at an actuator pressure of 6.5 bar (BS 4639:1987). Air brake actuators are available in a range of chamber diameters to enable selection of the appropriate brake application force to suit the size of lever arm, foundation brake and tyre size fitted to the vehicle (see Figure 2.8). Actuator stroke is typically ~75 mm (~3").
However, agricultural trailer braking systems differ from those fitted to road vehicles in so much as, whilst service braking is achieved via a similar ‘pressure-applied’ means, the method used to apply the foundation brakes in a parking mode is totally different. If an air-braked agricultural trailer is parked (detached), the air remaining in the trailer reservoir will pressurise the actuators and apply the brakes. However, if the reservoir pressure is released, either by leaks in the system or intentionally via the ‘manoeuvring’ or ‘shunt’ valve (see Figure 2.9), the brakes will release and the trailer can potentially roll away, or can be moved (albeit in an un-braked state) by a vehicle not equipped with pneumatic brakes.

The majority of pneumatically-braked large goods vehicles utilise pneumatic brake actuators which incorporate secondary chamber housing a compression spring. During normal vehicle operation, air pressure supplied to this chamber compresses the spring and renders it ineffective. If pressure is lost for any reason, intentionally say when parking or by accident, the spring extends and applies the foundation brakes. Pneumatically-braked agricultural trailers do not use such equipment and so are usually fitted with a separate mechanical system for parking brake application.

Whilst more complex, the dual-line braking system is inherently safer than single-line designs because of its failsafe characteristics (see Section 2.7). Should the trailer accidentally disconnect whilst in use, the red ‘supply’ line would fracture, triggering the relay-emergency valve to apply full pressure from the trailer reservoir (tank), applying the brakes in a similar manner to when parked (see above). Also, the location of the system control valve and energy reservoir directly on the trailer could be deemed to improve system response characteristics during braking, although certain hydraulic braking configurations have been shown to be competitive (Dodd et al., 2007). Air brakes are frequently regarded by users as superior to single-line hydraulic systems and with good reason. However, care must be taken to remain objective and compare like-with-like. Frequently a pneumatically-braked trailer is designed for higher speed (21 – 40 mph) use and will employ significantly larger foundation brakes than its (20 mph max. intended) hydraulically-braked counterpart. Also the brake application forces generated by a (non-load sensing) hydraulic brake actuation system may be substantially lower than those produced by a load-sensing pneumatic brake system fitted to the same trailer (see Section 2.4.3).

**Pneumatic Braking System Advantages:**
- i) Failsafe: stored energy source on trailer can apply brakes if it de-couples or the tractor brakes fail;
- ii) Potentially responsive system: good brake control;
- iii) Not particularly prone to contamination:- air release tends to expel dirt during coupling / de-coupling;
- iv) Readily incorporates load sensing and ABS functionality. 

**System Disadvantages:**
- i) More complex than hydraulic braking systems: less easy to understand and operate;
- ii) Power source often not already present on tractor;
- iii) Requires significant modification of conventional (20 – 25 mph / 32 – 40 km/h) tractors;
- iv) Complete (tractor and trailer) system more costly than hydraulic braking systems.
Figure 2.10  Typical hydraulic brake ram *(left)* and dual-supply (hydraulic/pneumatic) brake actuators *(right)*

### 2.4.3 Dual-Supply (Hydraulic and Pneumatic) Trailer Brake Actuation / Control

Depending upon their age and size (engine power), the tractors found upon many modern farms may be able to operate either single-line hydraulic trailer braking systems, or both single-line hydraulic and dual-line pneumatic trailer brakes: the latter configuration frequently being found upon tractors capable of greater than 25 mph / 40 km/h max. speed. Compatibility with the towing vehicle is, of course, an important issue when selecting a new trailer. One popular solution to the age-old "hydraulic or pneumatic?" question is to install dual-supply brake actuators on the trailer (see Figure 2.10) which, together with the necessary supply and control hardware, effectively provides both single-line hydraulic and dual-line pneumatic braking systems on the vehicle.

However, this solution is not as all-encompassing as one may imagine. UK road vehicle legislation (Statutory Instruments, 1984 & 1986) only permits the use of single-line hydraulic braking systems up to a maximum speed of 20 mph / 32 km/h (see Section 3.2). Above this speed (and up to 40 mph max.) commercial vehicle braking performance requirements apply and a dual-line failsafe braking system is required. The latter is usually satisfied by use of dual-line air brakes, but actually there is no legal requirement for pneumatic brakes at these (20 – 40 mph) operating speeds, but simply the level of functionality which is probably most easily achieved by their installation.

To satisfy these requirements trailer designers usually select the pneumatic components of dual-supply actuators to be capable of generating much greater forces (at rated operating pressures) than the hydraulic rams. By this means, when connected to suitably-sized foundation brake, the pneumatic system will generate a much greater braking effort than the hydraulic system, thereby meeting the higher performance levels stipulated for higher-speed (> 20 mph) operation, whereas the hydraulic system will satisfy the lesser (single-line) requirements for slower-speed use. Apparently a very convenient solution, just so long as the hydraulic braking system is not used when travelling at speeds above 20 mph / 32 km/h.
2.5 LOAD SENSING SYSTEMS

The majority of current agricultural trailer braking systems do not automatically adjust the braking effort generated depending whether the trailer is laden or empty. A typical 14-tonne trailer may have a (total) axle load of 4 tonnes when unladen; this would increase to perhaps 16 tonnes when laden. However, without load sensing, the theoretical maximum braking force which could be generated by the service brakes would be the same in both instances. Legislative minimum braking performance requirements relate only to trailers in fully-laden (worst-case) state. Consequently, a trailer whose braking system meets statutory performance requirements by bringing a laden vehicle safely to a stop, will potentially be over-braked when unladen, leading to wheel-locking during heavy braking, excessive tyre wear and a dangerous condition of lateral instability known as trailer swing. The purpose of a load sensing system is to reduce the trailer’s braking effort when unladen, thereby avoiding over-braking and possible instability.

This all sounds very plausible, but the single-line hydraulic braking systems used in the UK for the past 30 years very rarely incorporate load sensing systems, so why is the problem of over-braking and tyre wear not more widespread? Quite simply, the 25% braking efficiency systems stipulated for sub-20 mph agricultural trailers are generally incapable of generating sufficient braking effort to cause wheel-locking when unladen, except perhaps during emergency stops when extreme tractor brake pedal effort can result in abnormally-high trailer brake line pressure levels. In normal use over-braking problems will only really occur when system braking capacity is increased, for instance to comply with the performance requirements for higher speed (> 20 mph) travel (see Section 3.2).

For operational speeds above 20 mph, UK road vehicle legislation requires agricultural trailers to achieve the same braking performance as commercial vehicle trailers (45% efficiency). The adhesion coefficient between a trailer tyre and a dry road surface is typically ~0.6 – 0.7: consequently max. braking efficiency is usually limited by road surface adhesion to 60 – 70% (~ 50% in wet conditions). Braking Efficiency is the maximum braking force that can be developed by a vehicle’s system, expressed as a percentage of total axle weights (see Section 3.1). So if a trailer is designed to generate a braking force of at least 45% of its total (laden) axle weights, its braking efficiency will be substantially in excess of this value (and beyond road surface adhesion limits) when unladen, even during light braking. Trailer tyres are increasingly expensive, so a reliable, cost-effective solution to the problem is required: fortunately one has been used on road vehicles for many decades.
In principle, to reduce braking effort when unladen, the (hydraulic or air) pressure supplied to the brake actuators (hydraulic rams / air chambers) must be reduced when the trailer is partially-laden or unladen, full pressure being maintained when fully-laden: but to do this the trailer loading level must be determined accurately at all times, without manual intervention. A common solution is to insert a load sensing pressure reducing valve in the trailer brake circuit (see Figures 2.9, 2.11 & 2.12). This unit senses deflection of the trailer’s axle suspension springs via a cable or mechanical linkage (see Figures 2.11 & 2.12), greater deflection occurring under greater loads. That’s all very well if the trailer or trailed appliance has suspended axles: if not, deflection of the drawbar suspension spring (if fitted) can provide an alternative load-related signal, but this is generally acknowledged to be less effective.

A further problem is caused by the excessive stiffness of agricultural trailer suspension springs. These are usually over-specified to withstand the overloading frequently encountered in agricultural use; the downside being that spring deflection under the normal unladen – fully-laden load range can be very small: as little 25 mm for single-leaf parabolic springs; multi-leaf units being generally more flexible, typically giving ~40 mm deflection under full-load. Load sensing valves have a difficult job to do, being required to accurately reduce brake actuator pressure to less than 20% of input pressure when the trailer is unladen, but this can only be achieved if a reliable, accurate, trailer load-related signal is supplied to the valve in the first place. This remains a challenge for agricultural trailer manufacturers. Load sensing valves are readily available for hydraulic or pneumatic trailer braking systems, but until recently have usually only been fitted to pneumatically-braked trailers, whose higher-capacity braking systems (which are frequently intended for higher-speed use) required some form of performance reduction when unladen. It is for this reason that trailers fitted with dual-supply hydraulic and pneumatic braking systems will often only feature load sensing systems on the pneumatic system (see Figure 2.12); the hydraulic system being intentionally under-specified to preclude the need for (and additional cost of) hydraulic load sensing. There is, of course, no technical reason why both the hydraulic and pneumatic systems could not be so-equipped and deliver equivalent braking performance.
2.6 ABS

‘ABS’ or antilock braking systems are familiar to most passenger car, bus and truck drivers, although their use in agriculture is a relatively recent phenomenon and is largely restricted to agricultural trailers or certain ‘fast’ tractors. In essence ABS prevents a braked wheel from locking when the vehicle is over-braked: in reality it attempts to prevent brake-induced skidding on poor adhesion (slippery) surfaces where normal braking effort would be excessive (see Section 2.5). By the avoidance of wheel locking, vehicle directional stability and stopping distance (under the prevailing traction conditions) are improved.

Trailer ABS is essentially an electronic control system installed in addition to the existing brake control system. Wheel rotation sensors relay information to a trailer-mounted electronic control unit, which in turn operates pressure modulation valves in the brake actuator supply lines. Should the speed of one or more wheels reduce dramatically (indicating the onset of locking), brake line pressure is reduced (to regain wheel rotation) and then re-applied, to attempt to maximise braking under the prevailing traction conditions. ABS can be installed on the tractor and/or the trailer. Manufacturers of conventional tractors claim that significant design changes are required to permit tractor installation, whereas others (e.g. ICB Fastrac) install ABS as standard equipment. Irrespective of the towing vehicle, the last five years has witnessed a considerable increase in the installation of ABS upon agricultural trailers, albeit primarily those which are intended to be used at higher speeds.

The current UK statutory requirement for ABS braking on agricultural trailers applies only to vehicles used at speeds above 20 mph / 32 km/h. These vehicles do not enjoy the braking system performance dispensations granted to <= 20 mph agricultural vehicles (see Section 3.2), and so have to comply with commercial vehicle / trailer braking requirements. The latter has required ABS on trailers of more than 10 tonnes total axle load since the early-1990s: more recent legislative amendments (Statutory Instruments, 2001) have lowered the total axle mass threshold for ABS installation to 3500 kg. However, current draft European regulations for agricultural tractor and trailer braking performance (EEC, 2007) do not include a requirement for trailer ABS (see Section 3.3). Quite how this will affect UK practice remains to be seen.

Most trailer ABS systems are derived from truck applications and so are pneumatic in operation, but hydraulic systems do exist. Whilst ABS is gradually becoming more common on UK agricultural trailers, it is not necessarily for the right reasons. Some trailer manufacturers consider ABS an alternative to load sensing as a means of preventing wheel locking and tyre wear due to over braking, particularly if the vehicle suspension design does not readily lend itself to load sensing valve installation (see Section 2.5). However, braking equipment suppliers emphasize that ABS should be used to complement load sensing systems, rather than as a substitute for them. At present insufficient evidence of agricultural trailer braking system performance exists to substantiate either school of thought.

2.7 FAILSAFE BRAKING SYSTEMS

The purpose of a failsafe trailer braking system is to enable (or automatically effect) trailer brake application should the trailer become accidentally disconnected from the towing vehicle, or if the towing vehicle’s brakes should fail (or its power source become inoperative). Failsafe systems are a legal requirement for UK agricultural trailers used at speeds above 20 mph (32 km/h), but there is little evidence of their use upon hydraulically-braked vehicles. Excepting the systems used on smaller, car-type trailers which employ safety chains or cables to actuate the brakes in an emergency, the fundamental requirement for failsafe trailer braking is a stored energy reservoir on the towed vehicle. This (hydraulic or pneumatic) energy may then be directed to apply the trailer brakes in an emergency, potentially without driver intervention.

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As discussed in Section 2.4.2, a dual-line pneumatic trailer braking system incorporates this functionality as a standard feature. Breakage of the trailer air supply line (upon accidental trailer separation), results in the relay-emergency valve directing pressure from the trailer air reservoir to apply the brakes. Only if the reservoir were empty would there be an issue!

It is also possible for the trailer system to be configured so that a similar trailer braking response be triggered by the application of the tractor’s parking / secondary brake, as would potentially be the case in an emergency ‘engine-failure’ situation. Assuming that, in such a situation, the driver’s attention was not entirely focused upon attempting to maintain directional control of the vehicle combination via the (now) largely inoperative hydrostatic steering system!!

Failsafe systems are also widely available for hydraulic trailer braking systems, having been a statutory requirement since the 1990s for hydraulically-braked agricultural trailers used in France. Providing largely identical functionality to dual-line pneumatic systems, hydraulic pressure is stored on the trailer in one or more hydraulic accumulators, connected to a valve block containing two electro-hydraulic solenoid valves (see Figure 2.13). A conventional single hydraulic brake line connects the valve block to the tractor, but this is supplemented by an electric cable which feeds power from a tractor cab-mounted control box to the solenoid valves. Repeated trailer brake application, prior to driving off, charges the trailer-mounted accumulators: further normal brake use ensures they remain charged. Should the trailer disconnect accidentally, breakage of the electric power supply cable causes the solenoid valves to direct accumulator pressure to the brake rams, applying the trailer brakes. Similarly, in an emergency, a switch on the cab-mounted control box can also interrupt the trailer power supply, triggering the failsafe unit. Should accumulator pressure fall below acceptable levels, an in-cab buzzer and warning light are triggered, as would be the case for a pneumatic braking system.

Such electro-hydraulic dual-line braking systems are in fact functionally-equivalent to conventional dual-line pneumatic systems: it is also possible to incorporate a hydraulic load sensing system (see Figure 2.13 & Section 2.5). However, for use at speeds above 20 mph / 32 km/h ABS is still an additional requirement in the UK (Statutory Instruments, 2001).
3. AGRICULTURAL VEHICLE BRAKING SYSTEM PERFORMANCE REQUIREMENTS

3.1 INTRODUCTION AND TERMINOLOGY

As a safety-critical system upon an (occasional?) road-going vehicle, it would seem reasonable to expect statutory requirements to be stipulated for agricultural tractor and trailer braking system performance. This has in fact been the case for well over 50 years, albeit historically the braking requirements for agricultural tractors, trailers and associated trailed equipment were (and still are) considerably less stringent than those relating to other on-road vehicles, the justification for this relaxation being the low maximum speed of ‘true’ agricultural tractors (20 mph / 32 km/h) and that their primary use was off-road / in-field; on-road travel being a minority of total usage.

Over the last 15 – 20 years UK agriculture has changed a great deal, as have the tractors and trailers used by it. Farm numbers have decreased whilst average farm size has increased. Workforce and tractor numbers have reduced whilst tractor size / power and potential maximum speed have increased and operator comfort improved. The net result is that fewer, larger vehicles are now required to travel further and (in an ideal world) should spend less time doing so. This would all be acceptable if vehicle braking performance and associated statutory requirements had also adapted appropriately with time and technological developments. Legislation tends to lag behind technology unless serious public safety (or government policy) issues encourage action. Tractor braking systems have been developed to suit higher on-road speeds, spurred on by the necessity for EC Type-Approval testing prior to sale (EEC, 2003). However, whilst legislation exists for agricultural trailer (and trailed appliance) braking performance, it is in many ways outdated and not uniform across the European Union. Additionally, there is currently no requirement for Type-Approval testing of commercial or agricultural trailers prior to sale and no UK statutory requirement for regular roadworthiness testing of agricultural vehicles. So to summarise, the trailer braking regulations may well be outdated; there is no official means of ensuring trailer braking systems are legally compliant when sold; and once in-service it is up to the user to ensure the vehicle’s braking system continues to perform adequately, albeit there is no easy way of quantifying whether it is or not. Not exactly a very good position to start from!

All agricultural (and road vehicle) trailers are required to be fitted with service and parking brake systems. The service brake is responsible for bringing the vehicle to a halt, whereas the parking brake must ensure it remains stationary, particularly when de-coupled from the towing vehicle. Consequently all vehicle braking legislation stipulates separate performance requirements for the service and parking brake systems and frequently they are assessed by different methods (see Sections 4.2.1 & 4.2.2). The majority of road vehicle legislation specifies agricultural trailer service brake performance levels in terms of minimum acceptable braking efficiency at a given (hydraulic or pneumatic) actuation system (line) pressure.

\[
\text{Braking Efficiency} \left(\% \right) = \frac{\text{Brake Force Exerted by the Wheels}}{\text{Vehicle Weight}} \times 100 \quad (2)
\]

The term ‘Braking Efficiency’ is sometimes misunderstood, but it is relatively simple (see Equation 2). Confusion creeps in because, in the UK, we sometimes consider vehicle ‘mass’ (measured in kg or tonnes) to be the same as ‘weight’. This is not the case! ‘Mass’ (in kg) must be multiplied by 9.81 to convert to ‘weight’ (in Newtons); which is in fact a force. ‘Braking Efficiency’ represents the braking force generated by a vehicle as a proportion of the force the vehicle exerts downwards on the road surface, due to the action of gravity (see Section 4.2.1).
Road vehicle legislation usually specifies trailer parking brake performance in terms of the (up and/or down) gradient upon which the parking brake should hold the uncoupled trailer stationary when fully-laden. There is a great deal of logic in this approach, although assessing parking brake performance can require a degree of lateral thinking (see Section 4.2.2).

The following Sections are intended to provide an overview rather than an exhaustive examination of agricultural trailer braking legislation. Whilst every care has been taken to ensure accuracy, regulations are subject to interpretation. The reader is therefore advised to consult the regulations cited personally and obtain further, legal advice in critical instances.

### 3.2 CURRENT REQUIREMENTS

At present the UK and most other EU countries have their own specific rules and regulations for agricultural trailer braking performance. Unlike agricultural tractors, there are currently no standard, EU-wide braking regulations for agricultural trailers, although this is expected to change in the relatively near future (see Section 3.3). The situation is further complicated in many EU countries (including the UK) by national road regulations which specify alternative maximum road speed limits for agricultural vehicles, depending upon their specification. Enhanced braking system design and performance are frequently at the forefront of such constructional requirements to permit (legal) higher speed use.

Previous mention has been made of BS 4639 (BSI, 1987) and the DfT / HSE / MAFF industry guidance code (Agricultural Trailer Braking Systems - HSE (1979)) as technically-thorough reference documents which prescribe both desired levels of agricultural trailer braking performance and procedures for their assessment (see Section 2.4). However, no matter how comprehensive, these documents have no legal standing: in the UK agricultural vehicles must comply with the requirements of either UK or EU regulations (Directives).

Tractors sold in the EU are required to be Type-Approved, which involves passing a series of primarily safety-related checks and tests concerning, amongst other things, steering, braking, noise emissions, roll-over protective structures, seat belt anchorages, field of vision, position of lights, etc, prior to sale (EEC, 2003). Sample machines are assessed prior to the start of series production: dedicated EC Directives specify both performance requirements and the assessment procedures to determine regulatory compliance. In terms of agricultural vehicle braking performance, Directive 76/432/EEC (EEC, 1976) and its amendment 96/63/EC (EEC, 1996) deal with agricultural and forestry tractors but, critically, they do not extend to agricultural trailers or trailed appliances: a shortfall being addressed at present (EEC, 2007). Equally, the EC Type-Approval process is not currently applied to trailers or trailed appliances: whether this is due to lack of perceived need or, alternatively, suitable prescribed Directives, is debatable. In any case, the prescription of agricultural trailer braking performance currently falls to national legislation within EU member states which, coupled with local variations in maximum permissible tractor-trailer road speed, has led to an ‘interesting’ range of braking performance requirements in Western Europe (see Figure 3.1).

UK statutory requirements for road vehicle braking systems are defined by the Road Vehicles (Construction and Use) Regulations (Statutory Instruments, 1986 and subsequent amendments). Unfortunately, this document prescribes requirements for the design/construction and operation/use of all conceivable varieties of vehicles using UK public roads, not just for braking systems, but also for dimensions, steering, driver’s vision, emissions, instrumentation and numerous vehicle safety aspects. The reader can appreciate that this is a huge task. It is therefore hardly surprising that the resulting document can appear unwieldy and difficult to interpret, particularly when attempting to abstract information relating to a minority interest group such as agricultural vehicles.
Figure 3.1 Comparison of braking system performance requirements across the EU

UK legislation splits agricultural vehicles (specifically tractors and trailers) into two speed-related groups; namely those driven at no more than 20 mph (32 km/h) and those travelling between 20 and 40 mph (65 km/h). Agricultural motor vehicles (tractors) which exceed 20 mph are required to comply with the same Construction and Use (C&U) regulations as commercial vehicles, relating to (front and rear axle) suspension, tyres, safety glass, mirrors, windscreen wipers and washers, speedometers, horns, noise emissions, mudguards and, importantly, braking. The braking systems of these tractors must comply with C&U regulation 15 which, amongst other things, requires installation of ABS and a minimum 50% braking efficiency (see Figure 3.1).

Agricultural tractors which travel no faster than 20 mph are permitted to comply with a less demanding set of requirements (C&U Regulation 16), the key feature of which is a 25% minimum braking efficiency requirement. However, all (conventional) agricultural tractors sold in the UK in recent years will have been subject to EC Type-Approval, the braking performance requirements of which stipulate a minimum braking efficiency of 45%: consequently the lesser UK requirements are overruled, for tractors at least (see Figure 3.1).

The position for agricultural trailers is slightly more complicated. UK C&U regulations apply an identical maximum operating speed divide. Agricultural trailers drawn no faster than 20 mph (32 km/h) need only comply with Regulation 16 (25% min. braking efficiency, single line power braking, no ABS), but exceed 20 mph and (by default) C&U Regulation 15 applies (minimum 45% braking efficiency, twin-line failsafe braking system and ABS). What causes confusion is that whilst C&U Regulations make specific reference to agricultural tractors travelling up to 20 mph, to those travelling faster than 20 mph, and also to agricultural trailers not exceeding 20 mph, only passing reference is made to agricultural trailers travelling faster than 20 mph. The inference is that, when used above 20 mph, commercial trailer braking system requirements apply. At present there are no EU requirements to override (or clarify) this position.
Additionally, it is critically important to minimise any difference in braking efficiency between the towing and the towed vehicle (tractor and trailer). If the braking efficiency of both vehicles is identical, each will be brought to rest by their respective braking systems without any transfer of force to the other. However, if the braking efficiency of the trailer is, say, 25%, but that of the tractor is 50% (typical and currently legal in UK up to 20 mph), the trailer will attempt to decelerate at half the rate of the tractor, thereby attempting to push the tractor and transferring significant additional braking load onto it. It is highly undesirable that this situation can currently arise within UK regulations. However, if the trailer’s braking system was specified to comply with the higher-speed (> 20 mph) requirement (C&U Regulation 15), its >= 45% braking efficiency would almost match that of the tractor, eliminating force transfer during braking and creating a safer, more stable tractor-trailer combination. So perhaps it is not fair to blame the regulations, but rather the consumer for failing to purchase towed vehicles fitted with sufficiently-capable braking systems!

One source of confusion (and/or ‘interpretation’) arises from the failure of current UK C&U regulations to specify braking system actuating (line) pressure value(s) at which the stipulated performance requirements should be achieved. As discussed in Section 4.2.1, trailer braking performance is highly dependent upon the line pressure used. Both BS 4639 (BSI, 1987) and the DfT / HSE / MAFF industry guidance code (Agricultural Trailer Braking Systems - HSE (1979)) specify reference line pressures of 100 bar (hydraulic) or 6.5 bar (pneumatic) at which the minimum braking efficiency values should be attained. Regrettably, these requirements were not transferred to C&U Regulations.

A further C&U shortfall concerns agricultural trailer parking brake performance. BS 4639:1987 and the DfT/HSE/MAFF guidance code both stipulate that the parking brake should hold a fully-laden, uncoupled trailer stationary on an 18% gradient. C&U regulations apply similar requirements to most wheeled vehicles, albeit specifying a 16% gradient: however, the parking brakes of agricultural trailers are exempted from this precise requirement, instead simply being required to prevent at least two of the trailer’s wheels from revolving when it is not being drawn.

3.3 FUTURE REQUIREMENTS

It may be considered folly to attempt to predict future (legislative) braking performance requirements which may apply to agricultural trailers (and tractors). Under normal circumstances this would be true but, at the time of writing, the revision of European (agricultural) tractor and trailer braking legislation is reaching an advanced stage (EEC, 2007) and it seems very likely that, as a consequence, some significant changes will in time be made to the braking system requirements which apply to (new) UK agricultural vehicles.

Firstly, a few qualifying statements. What follows is an informed interpretation of recent (political and technical) developments and negotiations within the EC. The matter has yet to be concluded and so it would be most premature to believe that the following is a statement of fact: it most certainly is not. Additionally, any revised pan-European braking legislation will only apply to new vehicles manufactured or brought into service after a specific point in time. Unless extremely safety critical, such legislation is very rarely retrospective (i.e. applies to vehicles already in use). Any desire to improve the braking capability of existing vehicles (assuming them to be compliant with current legislation) is entirely at the discretion of the owner / operator. However, as discussed in Section 5.4, there may be compelling economic reasons for doing so.
Returning to EU agricultural trailer braking legislation, Figure 3.1 shows that current UK statutory performance requirements both exceed and fall below those of France and Italy, depending upon the intended max. speed of operation. France requires a minimum trailer braking efficiency of 35% whereas Italy stipulates 40%. The UK request 25% (min.) up to 20 mph (32 km/h), but this jumps to 45% (min.) at speeds above 20 mph. Not a bad position perhaps, on the assumption that those trailers travelling faster than 20 mph comply with the more stringent requirement: unfortunately this is not always the case.

The current draft EU agricultural braking regulations (EEC, 2007) are intended to replace Directives 76/432/EEC & 96/63/EC and in so doing encompass both tractor and trailer / trailed appliance braking requirements. The draft regulations incorporate speed break-points, much in the way of UK C&U regulations. The exact value(s) of the threshold(s) is currently the subject of much negotiation but, irrespective of the precise outcome, the implications for UK agricultural vehicle operation are likely to be unaffected, because the requirements for vehicles travelling at or above 25 mph (40 km/h) have largely been agreed.

During development of the regulations in conjunction with European agricultural engineering industry trade associations, the European Commission contracted TRL Ltd (the former UK Transport Research Laboratory) to investigate the technical and economic feasibility and likely impact of the proposed regulations. Industry committees had already proposed much of the regulation content, but the TRL investigation (Dodd et al., 2007) attempted to determine the feasibility of the proposals and determine if they were adequately (or excessively) ambitious.

The current (draft) EU Regulations (EEC, 2007) undoubtedly represent a major improvement in the legislative control of tractor-trailer braking performance. Overall it is likely that they will have a greater impact upon agricultural trailer and trailed appliance braking performance than upon that of modern agricultural tractors. At present, the proposed draft regulations address many of the shortfalls present in national tractor-trailer braking legislation, by requiring:-

**Trailer / Trailed Equipment Braking**

- Substantially greater trailer braking performance *(min. 50% braking efficiency for vehicles operating above 30 km/h, i.e. all UK trailers)* (see Figure 3.1);
- Specific system line pressure values at which minimum braking performance must be attained *(115 bar – hydraulic: 6.5 bar pneumatic)*;
- All trailer / trailed equipment braking systems to be dual-line and fail-safe *(brake application upon accidental separation)*;
- Braking systems can be dual-line pneumatic, dual-line hydraulic or single-line hydraulic plus electrical *(failsafe)* connection;
- Secondary *(backup)* brake application system required on larger trailers and trailed equipment, in case of towing vehicle brake / engine failure. Requires storage of energy *(air reservoir, hydraulic accumulator or springs)* upon trailer;
- Max. trailer brake reaction time *(0.6 seconds from application of tractor brake control)*;
- Trailer *(service)* brakes to be applied on application of the tractor parking brake;
- Trailer parking brake to hold fully-laden, de-coupled vehicle on an 18% gradient
- Introduction of Type-Approval for trailers and trailed equipment: vehicle designs required to demonstrate compliance with EU regulations prior to sale.
Whilst perhaps appearing somewhat dramatic, when compared with the current UK C&U braking requirement for above 20 mph operation, the proposed EU trailer / trailed equipment braking regulations are not particularly severe. Indeed, the current draft EU regulations do not require the installation of ABS braking systems on trailers / trailed equipment and are unlikely to require ABS on ‘conventional’ tractors. It remains to be seen whether the eventual introduction of the regulations will result in a relaxation of the UK ABS requirement (see Section 2.6).

As this report will go on to show (see Sections 5 & 6), the EU requirements can most certainly be met with currently-available trailer braking equipment, albeit not necessarily that used on the majority of agricultural trailers currently in-service. Additionally, the cost-penalty of such system improvements is again, not very great and, in the light of potential tractor braking system repair costs, probably a reasonable and worthwhile investment.

Importantly, the proposed EU braking regulations will potentially serve to remove confusion from the field of tractor-trailer braking, by stating clear system performance requirements. The industry will also be well-served by the reduction in (or hopeful elimination of) the disparity between tractor and trailer braking performance requirements. This will both improve vehicle combination stability, enhance safety and almost certainly reduce tractor-trailer braking system repair costs. The key question ? When will the regulations come into force ? Certainly not before 2010 and possibly not before 2011-12. This is one facet which the author is unable to predict with any certainty.
4. IN-SERVICE TRAILER BRAKING INVESTIGATION: – METHODOLOGY

4.1 TEST VEHICLE SELECTION

It was recognised at the outset that the number of test vehicles which could be targeted by the investigation would be limited. Consequently it was of the upmost importance that the test trailers and trailed appliances were highly representative of units in everyday frontline use on UK farms. It would of course have been possible to select vehicles in sub-optimum condition, in order to obtain potentially-dramatic test results, but it was felt this would undermine the validity of the overall investigation and invite criticism of the data generated. Consequently, the test vehicles (see Table 4.1 & Figure 4.1) were selected according to the following criteria:-

- **Size / Capacity / Popularity:** Relevance to modern UK farming practice. Representative of units in widespread use;
- **Recognised Product:** Bearing a manufacturer’s plate stating permissible loading levels;
- **Age / Condition:** Ideally spanning an age range of 1 – 20 years, but to be capable of further 10 years frontline use (i.e. would justify investment in running gear / braking system upgrade);
- **Braking System Specification:** Whilst all featured single-line hydraulically-actuated braking systems, test vehicles were selected to provide a range of (foundation) brake sizes, reflecting industry design practice.

**Table 4.1:** Trailers and trailed appliances investigated

*(N.B.: All featured single-line hydraulic braking systems)*

<table>
<thead>
<tr>
<th><strong>Vehicle Type</strong></th>
<th><strong>Year of Manufacture</strong></th>
<th><strong>Nominal Capacity</strong></th>
<th><strong>Undergear Type</strong></th>
<th><strong>Brake Size (drum Ø x shoe width (mm))</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Tandem-axle Grain Trailer</td>
<td>1999</td>
<td>14 tonnes</td>
<td>Mono-leaf spring</td>
<td>400 x 80</td>
</tr>
<tr>
<td>2 Tandem-axle Grain Trailer</td>
<td>2001</td>
<td>14 tonnes</td>
<td>Multi-leaf spring</td>
<td>400 x 80</td>
</tr>
<tr>
<td>3 Tandem-axle Grain Trailer</td>
<td>1987</td>
<td>14 tonnes</td>
<td>Mono-leaf spring</td>
<td>300 x 90</td>
</tr>
<tr>
<td>4 Tandem-axle Grain Trailer</td>
<td>2007</td>
<td>16 tonnes</td>
<td>Mono-leaf spring</td>
<td>420 x 180</td>
</tr>
<tr>
<td>5 Tandem-axle Grain Trailer</td>
<td>1991</td>
<td>12 tonnes</td>
<td>Mono-leaf spring</td>
<td>420 x 180</td>
</tr>
<tr>
<td>6 Tandem-axle Grain Trailer</td>
<td>1978</td>
<td>16 tonnes</td>
<td>Mono-leaf spring</td>
<td>420 x 180</td>
</tr>
<tr>
<td>7 Tandem-axle Dump Trailer</td>
<td>1993</td>
<td>14 tonnes</td>
<td>Rocking beam</td>
<td>400 x 80</td>
</tr>
<tr>
<td>8 Tandem-axle Flatbed Trailer</td>
<td>2007</td>
<td>10 tonnes</td>
<td>Multi-leaf spring</td>
<td>300 x 60</td>
</tr>
<tr>
<td>9 Tandem-axle Slurry Tanker</td>
<td>1996</td>
<td>2000 gallons</td>
<td>Rocking beam</td>
<td>300 x 90</td>
</tr>
<tr>
<td>10 Big Square Baler</td>
<td>2007</td>
<td>-</td>
<td>Single, rigid axle</td>
<td>400 x 80</td>
</tr>
</tbody>
</table>
Figure 4.1 Trailers and trailed appliances investigated
4.2 BRAKING SYSTEM PERFORMANCE MEASUREMENT

4.2.1 Service brake performance

Whilst employing the same (foundation) brake components, on the majority of UK agricultural trailers the service and parking brake actuation systems are completely different. The performance requirements are also system-specific, necessitating different approaches be employed for service and parking brake performance assessment.

In the case of the trailer service braking system, the parameter used to define performance is typically Braking Efficiency. As previously discussed in Section 3.1, this is the sum of the tangential (braking forces) developed at the periphery of a vehicle’s wheels expressed as a percentage of the total weight (in Newtons) supported by those wheels (see Equation 3 & Figure 4.2). The majority of road vehicle legislation specifies agricultural trailer service brake performance levels in terms of minimum acceptable braking efficiency at a given (hydraulic or pneumatic) actuation system (line) pressure. Consequently, to determine trailer service braking performance (efficiency), given knowledge of the trailer’s maximum permissible (plated) axle loads, it is necessary to measure the braking force generated by the trailer system during simulated emergency stop procedures at a range of braking system actuation pressures (see BS 4639:1987).

\[
\eta_{(TL)} = \left[ \frac{F_{(TL)}}{m_{(TL)} \times g} \right] \times 100\% \tag{3}
\]

where:-

- \( \eta_{(TL)} \) = trailer braking efficiency (\%)
- \( F_{(TL)} \) = trailer braking force (Newtons)
- \( m_{(TL)} \) = trailer (total) axle load (kg) \((as \ stated \ upon \ manufacturer’s \ plate)\)
- \( g \) = acceleration due to gravity \((9.81 \text{ m/s}^2)\)
During normal operation the tractor and trailer braking systems are applied simultaneously, the former supplying power to and/or triggering operation of the latter. However, this characteristic complicates accurate measurement of trailer braking force, particularly as this may well be smaller than that generated by the tractor. It is possible to overcome this restriction by simultaneously measuring the horizontal thrust (or pull) generated at the tractor-trailer coupling during the braking test, but this is not a trivial task, particularly in the case of unbalanced-type trailers typically used in the UK, which can impose vertical loads of 3000 kg plus on the tractor coupling when laden. A far simpler and arguably more accurate approach is proposed by BS 4639 (BSI, 1987) and is also offered as an option within the technically-equivalent ISO 5697 (ISO, 1982) and the draft EU tractor-trailer braking regulations (EEC, 2007). This methodology was therefore selected for the purposes of service braking performance evaluation within this investigation.

This technique involves derivation of the trailer braking force by measurement of deceleration of the tractor-trailer combination during a series of emergency stop procedures, but with braking effort being supplied solely by the trailer brakes. This would initially appear to result in a much reduced deceleration performance, but by simple compensation for the larger (tractor + trailer) mass that is being brought to rest, it is possible to calculate the braking force generated by the trailer (see Equation 4) by use of Newton’s 2nd Law \( F = ma \). Substitution of the trailer braking force value in Equation 3 subsequently permits derivation of the trailer braking efficiency at the actuating (line) pressure used.

\[
F_{(TL)} = \left(m_{(TR)} + m_{(TL)} \right) d_m \tag{4}
\]

where:
- \( F_{(TL)} \) = trailer braking force (Newton)
- \( m_{(TR)} \) = tractor (total) axle load (kg) \( \text{(incl. trailer drawbar load)} \)
- \( m_{(TL)} \) = trailer (total) axle load (kg)
- \( d_m \) = tractor-trailer mean fully-developed deceleration \( (\text{m/s}^2) \)

\text{N.B.:} \quad \text{In the case of unbalanced trailers (as popular in the UK) the tractor mass is considered to include the load transferred by the trailer drawbar \( \text{(up to 3000 kg)} \) \( \text{(see Figure 4.2).} \) In terms of service braking system performance, the deceleration of this additional load becomes the responsibility of the tractor.}

In many current procedures for tractor and/or trailer braking performance determination (e.g. ISO 5697:1982, BS 4639:1987, EC Directive 76/432/EEC), vehicle (mean) deceleration is derived from the stopping distance during test; namely the distance covered from the moment when the driver begins to operate the brake control until the moment when the vehicle stops. This approach introduces a degree of variability because of the inclusion of braking system ‘response’ and ‘pressure build-up’ times in the overall stopping time / distance / deceleration period. Whilst not of great consequence in the case of (historically) slower agricultural vehicles, increasing maximum road speed capability has led to the progressive adoption of ‘Mean Fully-Developed Deceleration’ \( (d_m \text{ or MFDD}) \) from on-highway vehicle practice, in place of the current ‘Mean Deceleration’ \( (a) \). Mean fully-developed deceleration is simply the deceleration of the vehicle during the braking cycle, albeit averaged between 80% and 10% of the initial test speed at which the braking control is actuated (see Equation 5). This approach therefore removes the influence braking system response time and (hopefully) generates more repeatable results.
\[ d_m = \frac{v_b^2 - v_e^2}{2(s_e - s_b)} \]  

where:

- \( v_b \) = vehicle speed at 0.8 \( v_1 \) (m/s)
- \( v_e \) = vehicle speed at 0.1 \( v_1 \) (m/s)
- \( v_1 \) = initial vehicle speed (m/s)  \( \text{must be >=98\% of prescribed test speed} \)
- \( s_b \) = distance travelled between \( v_1 \) and \( v_b \) (m)
- \( s_e \) = distance travelled between \( v_1 \) and \( v_e \) (m)

It is not possible to derive mean fully-developed deceleration by measurement of vehicle stopping distance after the braking event: rather it is necessary to record the distance travelled with respect to time throughout the braking cycle, thereby permitting derivation of vehicle speed and deceleration. This necessitates use of a speed / distance sensor, a common automotive solution being an instrumented 5th wheel attached to the test vehicle. Such a device was utilised during this investigation \( (JPS\ Engineering\ type\ FW\ MkII) \). Attached to the rear axle or chassis of each test trailer / trailed appliance \( \text{see Figure 4.3} \), this unit was capable of measuring distance travelled with a resolution of ±1 cm.

The 5th wheel interfaced with a bespoke electronic signal conditioning and data acquisition system mounted in the tractor cab \( \text{see Figure 4.3} \). Based upon a ruggedised laptop computer, the system simultaneously recorded trailer brake line pressure during the braking test cycle, this information being generated by a pressure transducer \( (Maywood\ Micro\ Gage\ type\ P102) \) mounted just upstream of the tractor-trailer brake pipe connector \( \text{see Figure 4.4} \). To permit operation of only the trailer braking system during the braking cycle, hydraulic pressure was derived from one of the tractor’s spool valves, the tractor system pressure being reduced accordingly by an externally-mounted adjustable, flow-compensated pressure-reducing valve \( (Vickers\ type\ ECT\ 06F\ 10T8 - \text{see Figure 4.4}) \).

**Figure 4.3** Instrumented 5th wheel \( \text{(left)} \) and laptop-based in-cab data acquisition system \( \text{(right)} \)
As previously discussed, BS 4639 (BSI, 1987) advocates measurement of trailer braking performance at a range of line pressures to map the system’s characteristics. The same standard states that, for hydraulic systems, a trailer braking efficiency of at least 25% should be achieved at a coupling head pressure of 100 bar. Additionally, it is stated that a hydraulic trailer braking system should be capable of withstanding a maximum pressure of 150 bar. The hydraulic trailer braking valves of most modern UK tractors are typically capable of delivering 135 – 140 bar max. pressure. Consequently, for the purposes of this investigation, three set-point line pressures (~70, 100 and 130 bar) were chosen to encompass the range likely to be experienced by the test trailers during everyday use.

Prior to evaluation of service brake performance, the ‘as-found’ off-farm trailers and trailed appliances were routinely inspected to identify any immediately-obvious faults present in the braking systems (e.g. leaking hydraulic hose couplings, seized brake actuation rams / linkages). Due to safety considerations (during travel to the test site), these faults were rectified, but in general were both rare and of a minor nature. The unladen axle and drawbar loads of each test trailer / trailed appliance were determined by use of instrumented weighpads. Following this each trailer was ballasted (using soil or steel weights) to axle and drawbar loading levels closely approaching those stated on the manufacturer’s plate. The slurry tanker was filled to capacity with liquid: the big baler was tested unladen, its unladen mass being 92% of its maximum permissible mass. Test vehicle laden axle and drawbar masses were measured both by weighpads and subsequently upon a public weighbridge.

The following test procedure was used to determine trailer service brake performance:-

- Tractor and trailer driven at 32 km/h (20 mph) on flat, dry tarmac (see Figure 4.5);
- Trailer brakes (only) applied (via tractor spool valve and pressure reducing valve) to bring combination to a halt;
- Trailer velocity (distance travelled) and brake line pressure logged with respect to time, permitting calculation and in-cab display of stopping distance, mean deceleration, mean fully-developed deceleration, trailer braking force and trailer braking efficiency
- Test repeated 4 times (each) at brake line pressures of ~ 70, 100 and 130 bar, ensuring brake drum temperature was less than 100°C prior to each test replicate.

This entire procedure was subsequently repeated following disassembly, maintenance and readjustment of each trailer’s braking system.
Figure 4.5  Trailer undergoing service brake performance test (left) - view of operator’s display during test (right)

An initial (pre-test) speed of 32 km/h (20 mph) was chosen to coincide with the maximum legal road speed for single-line, hydraulically-braked agricultural trailers in the UK (Road Vehicles (Construction and Use) Regulations, 1986). In fact for the purposes of Type-0 (cold) braking performance tests, the precise initial speed is not of great consequence, given that it is representative of the road speed capability of the vehicle and it is achieved repeatably (and measured accurately) during the test procedure. To assist the operator in this, a dash-mounted display was provided (see Figure 4.5), the left-hand dial indicating vehicle speed and the right-hand denoting trailer brake line pressure. Having specified the target (initial speed and line pressure) values required for a given test run, vertical orientation of the dials indicated that the correct parameter levels had been achieved during each test.

Figure 4.6  Laptop PC display of test parameters immediately following braking test
Following each individual braking test cycle, the stopping distance, mean deceleration and mean fully-developed deceleration of the tractor-trailer combination, the average brake line pressure and the mean braking force generated by the trailer’s service braking system, were displayed by the in-cab laptop PC data acquisition system (see Figure 4.6). However, having been previously programmed with the respective total axle loads of tractor and trailer, the PC also calculated the test trailer’s braking rate and braking efficiency. Braking Efficiency values were then plotted against the mean brake line pressure recorded during each test replicate and a best-fit regression line added to the data arising from each trailer’s series of tests conducted in ‘As-Found’ and ‘Post-Maintenance’ condition, respectively (see Figure 4.8).

If the trailer service braking system was in an adequate state of repair, braking efficiency typically demonstrated a strong linear increase with respect to line pressure: any absence of this characteristic was a cause for concern and indicative of system wear, poor adjustment or other faults. As expected, trailer service braking system performance usually improved significantly following workshop maintenance and re-adjustment. In fact Figure 4.8 depicts performance data from a test trailer (Vehicle No.1) which, if anything, was in a better-maintained condition than many in its original ‘As-Found’ state. Despite this, its braking performance still increased substantially following maintenance (see Appendix 2.1). It should also be noted that, initially, even this vehicle failed to meet the UK statutory trailer service braking performance requirement of 25% efficiency at 100 bar (hydraulic) line pressure (see Figure 4.8). Nonetheless, following maintenance this requirement was satisfied, albeit not by a significant margin.

Figure 4.7  Forward speed and brake line pressure time histories of 2 trailers during service brake tests. (*Trailer 2 has significantly greater braking performance than Trailer 1*)
4.2.2 Parking brake performance

BS 4639 (BSI, 1987), in common with most other standards and regulations concerning agricultural vehicle braking, specifies parking brake performance in terms of the magnitude of (up or down) gradient upon which a given vehicle should remain stationary, following application of the brake by (hand or foot) forces not exceeding certain levels. A gradient of 18% is common to much current and proposed regulations (see Section 3): however a more usual approach to evaluation of trailed vehicle parking brake performance is a ‘gravity simulation test’. In this instance the test trailer is ballasted to its rated capacity and parked on a flat surface. With the parking brake applied, the vehicle should be capable of resisting a horizontal force equivalent to the gravitational force which would attempt to cause the vehicle’s motion down an 18% slope.

To be in complete compliance with BS4639:1987, the towing force should be applied (successively) in both forward and reverse directions. For the sake of practical expediency during this investigation the test was conducted in the forward direction only. Also, rather than attempt to determine whether the stipulated level of resistance could be achieved, the force required to cause trailer motion with the parking brake applied was recorded. This was then compared with that stipulated for the laden mass of the trailer under test. This is given by Equation 6 below.

\[ F_{p(TL)} = 0.18 \times m_{(TL)} \times g \]  

(6)

where:

- \( F_{p(TL)} \) = trailer parking brake force (Newtons)
- \( m_{(TL)} \) = trailer (total) mass (kg) \( \text{ (total axle load plus drawbar load) } \)
- \( g \) = acceleration due to gravity \( 9.81 \text{ m/s}^2 \)
It will be noted that when assessing trailer parking brake performance, contrary to the service brake procedure, the entire trailer mass (including the drawbar load normally transferred to the tractor) is taken into consideration. This is entirely logical, given that a parking brake system would usually be required to prevent motion of the trailer or trailed appliance when disconnected from the towing vehicle, the worst-case scenario being when fully-laden. To give some indication of the level of restraining force expected of a trailer parking brake system, a trailer complying with the current UK maximum mass limit (18,290 kg) would be required to generate a horizontal force of not less than 3.23 tonnes (32,296 Newtons).

Figure 4.9  Trailer parking brake performance test:- application of brake (left) and force transducer and drawbar support installation (right)

Performing the parking brake test was a relatively simple matter and utilised much of the instrumentation and data acquisition system used for service brake testing. The trailer was suitably ballasted (test usually conducted prior to or immediately following a service brake test) and the vehicle attached to the test tractor. In order to permit measurement of the force required to cause forward motion, a 5 tonne capacity strain gauge force transducer (Novatech Type F204, ser. no. 6437) was inserted between the tractor pickup hook and the trailer drawbar ring (see Figure 4.9). The trailer drawbar was then supported in the vertical plane by means of a frame attached to the tractor’s three-point linkage and the instrumented 5th wheel unit (see Figure 4.3) attached to the trailer chassis to indicate trailer motion.

The test was performed by attempting to drive forward as slowly as possible. The laptop-based data acquisition system (see Figure 4.3) simultaneously logged the output of the force transducer and the 5th wheel until a prescribed (very small) distance had been travelled. The mean horizontal force recorded during that period was then displayed. This trial was repeated a number of times, both with the parking brake released and when fully-applied, in order to determine the magnitude of motion-resisting force contributed either by trailer rolling resistance (on smooth, flat concrete) or by the parking brake system. The results obtained from each test vehicle are presented and discussed in Appendix 2.
4.3 TEST VEHICLE BRAKING SYSTEM MAINTENANCE

A major part of the investigation involved servicing and adjusting the braking systems of each test trailer / trailed appliance to an extent that could be performed in a well-equipped farm workshop. The purpose being to return each vehicle’s braking system to a level of functionality which could, in all probability, be maintained throughout the machine’s working life, if given sufficient, regular attention. This maintenance activity was performed following the assessment of each test vehicle’s service and parking brake performance in ‘As-Found’ (off-farm) condition, prior to re-evaluation of braking system performance ‘post-maintenance’. This enabled any possible inadequacies in trailer braking system performance to be attributed either to insufficient on-farm maintenance whilst in-service, to inadequate braking system specification at time of manufacture, or to a combination of both factors.

Maintenance activities typically included:-

- Wheel and brake drum removal;
- Brake drum & shoe cleaning and inspection;
- Brake shoe replacement *(if necessary)*;
- Service and parking brake actuator linkage lubrication and free-travel adjustment;
- Hydraulic system leak rectification *(if necessary)*;
- Wheel bearing lubrication and adjustment;
- Wheel stud replacement *(if necessary)*;
- Suspension system lubrication;
- General tightening of wheel nuts and suspension system fasteners.

The braking systems and running gear of each test trailer / trailed appliance was serviced according to the recommendations the respective vehicle and/or axle manufacturer. In fact, as explained in Section 2, most of the axles, and therefore the foundation brakes, the actuating camshafts and brake lever arms used on UK agricultural trailers and trailed appliances, are supplied by a very small number of manufacturers (e.g. ADR/Colaert, Granning/ROR, GKN/FAD and BPW). Consequently, a relatively high level of commonality exists within the trailed vehicle fleet, axle and foundation brake specification and construction being influenced primarily by gross mass, number of axles and industry practice at the time of manufacture. However, one area of considerable variation concerned the selection and installation of (service) brake actuators (rams) upon the axles. Sizing and installation of these components has typically been the responsibility of the trailer manufacturer, rather than the axle supplier. The former may also select the design of brake lever arm / slack adjuster and, given the range options provided (see Section 2.3), the brake ram attachment point upon this component. As previously discussed, this can significantly affect the brake camshaft torque and (hence) the braking force which a given size of foundation brake can generate when actuated by a brake ram of given diameter. Therefore, even for an identical axle and/or foundation brake, the scope for variation of actuator size and configuration are substantial.

To ensure a common approach and sufficient attention to detail during servicing of each test vehicle, a maintenance record sheet was devised (see Appendix 1) to record pertinent details of vehicle specification, condition of the braking system ‘as-found’ (e.g. brake lining thickness and actuator (ram) travel), and service brake actuator travel following adjustment. General comments were also recorded regarding the condition of the braking system components and steps taken to rectify those issues deemed to require attention.
Generally, other than cleaning, lubrication and rectification of obvious faults (e.g. loose components, seized parking brake levers), the majority of attention focussed upon two areas:

i) Ensuring adequate thickness of brake shoe friction material for further service (typically 2 mm (min.) for bonded linings and 5 mm (min.) for riveted linings);

ii) Adjustment of brake lever arm vs. camshaft position to minimise brake actuator (ram) travel (whilst not causing brakes to bind when released), thereby providing scope for accommodation of future brake lining wear and consequent increase in actuator travel prior to the ram reaching its end-travel (maximum extension).
5. ANALYSIS AND DISCUSSION OF RESULTS

5.1 TRAILER BRAKING SYSTEM PERFORMANCE

It is arguably fair criticism to question the relatively small number of test vehicles targeted by this investigation but, as mentioned in Section 4.1, this resource-induced restriction was recognised at the outset. Steps were subsequently taken to ensure that the test trailers and trailed appliances selected for study were highly representative of (hydraulically-braked) frontline units in everyday use on medium – large UK farms, the selection if anything leaning towards better rather than poorer condition examples. Upon reflection, a range of different (hydraulic) braking system designs and capabilities were encompassed, thereby maximising the applicability of the findings to typical agricultural trailer and trailed appliance use in the UK. Figure 5.1 depicts the age distribution of the test vehicles. 30% were less than 1 year old; a further 40% had seen less than 15 years service, whereas the remaining 30% were between 16 and 30 years old.

![Figure 5.1 Test vehicle age range](image)

When viewed overall, the service brake performance of the test trailers raises some cause for concern (see Figure 5.2). As discussed in Section 3.2, current UK Road Vehicles (Construction and Use) Regulations require the service braking systems of agricultural trailers intended for use at not more than 20 mph “to be capable of achieving a braking efficiency of not less than 25%”. In off-farm ‘As-Found’ conditions, 90% of the test vehicles failed to achieve this level of performance at the 100 bar reference line pressure level stipulated by BS 4639 (BSI, 1987). Only one trailer (No. 4) met the stipulated performance requirement: it was 3 months old.

Following (farm) workshop maintenance / overhaul, 40% of the test vehicles achieved the stipulated service brake performance level: a further 20% came close to the requirement, but 40% of these (modern and apparently serviceable) vehicles still failed to meet statutory performance requirements (see Figure 5.2).
As indicated by Figure 5.2 (and discussed in greater detail in Appendix 2), all test vehicles which received workshop servicing / maintenance demonstrated a significant improvement in service brake performance. The degree of improvement typically exceeded 10% for vehicles-
-less than 1 year-old (approximately one quarter of the test vehicle population): a further quarter demonstrated a ~35-40% improvement in braking efficiency. The remaining population quarters returned improvements of ~50-80% and ~120-160% respectively. The small test vehicle sample undoubtedly limits the degree of data analysis possible, but nonetheless the overall message is undoubtedly one highlighting the need for more frequent and thorough maintenance of current trailer braking systems, inadequate as some of them they may be in any case. (N.B.: The braking systems of vehicles Nos. 4 and 9 were not serviced during the investigation due to (i) the ‘as-new’ condition of the former and (ii) the latter having recently been serviced by a competent vehicle workshop).

Further analysis of the test data shows that service brake performance was not a function of test trailer / trailed appliance age (see Figure 5.3): indeed 17 and 30 year-old trailers met current UK requirements, albeit after workshop maintenance (see Appendix 2). In other words, whilst appropriate maintenance was undoubtedly important, the trailer’s braking system specification would always be the ultimate factor limiting service brake performance.

When collected for testing, 40% of the test vehicles were found to have inoperative (seized) parking brakes. Once operational, the performance of the parking brake systems were, with one notable exception, extremely poor (see Figure 5.4). Workshop servicing produced improvements in 40% of instances, but just as frequently caused no beneficial effect. This situation reflects poor parking brake system design and an inherent inability of an operator to apply sufficient (manual) force to the vehicle’s braking system to produce the desired level of braking effort. It is also a reflection of the sad fact that, whilst both BS 4639 (BSI, 1987) and the DIT / HSE / MAFF industry guidance code (Agricultural Trailer Braking Systems - HSE (1979)) specified levels of parking brake performance for agricultural trailers, these were never transposed to subsequent revisions of UK C&U Regulations. Consequently, there is currently no precise UK statutory requirement for agricultural trailer parking brake performance and this is reflected in the marketplace offerings.

![Figure 5.4 Test vehicle parking brake performance](image-url)

(Data presented left → right for vehicle nos 1 – 10)
5.2 BRAKING SYSTEM SHORTFALLS

The precise reasons for poor braking performance of individual test trailers / trailed appliances targeted by the investigation are discussed in Appendix 2: however, concentrating upon the service braking system, a number of themes were recurrent, namely:-

i) Insufficient or total absence of braking system maintenance (see Figure 5.5);

ii) Inadequate foundation brake size for typical operating speeds;

iii) Insufficient brake application force:-

- Brake rams reaching end-travel (see Figure 5.6)
- Brake ram diameter too small
- Insufficient brake lever arm radius
- Inefficient brake ram - lever arm angle (see Section 2.3)

These fundamental failings fall into two basic categories, namely:-

i) Inadequate vehicle (braking system) specification for current (typical) usage. Whether this is a result of poor vehicle design, inappropriate selection at time of purchase, or change in intensity of usage (higher max. speed) is open to debate;

ii) Insufficient levels of regular maintenance to ensure acceptable levels of service brake performance, either under normal circumstances or, more importantly, to attempt to compensate for the greater demands imposed by regular vehicle operation at max. speeds of 25 mph / 40 km/h and above.

Whilst a perpetually-thorny subject, issues of trailer brake maintenance can be reduced to much more manageable proportions, if only a little forethought is given when purchasing a new trailer / trailed appliance or when upgrading an existing vehicle. Certain designs of braking system components can make adjustment and maintenance so much easier and more likely to be undertaken during everyday use.

During this investigation, other than cleaning, lubrication and rectification of obvious faults (e.g. loose components, seized parking brake levers), the majority of maintenance effort was focussed upon two specific areas:-

i) Ensuring adequate thickness of brake shoe friction material for further service (typically 2 mm (min.) for bonded linings and 5 mm (min.) for riveted linings);

ii) Adjustment of brake lever arm vs. camshaft position to minimise brake actuator (ram) travel (whilst not causing brakes to bind when released), thereby providing scope for accommodation of future brake lining wear and consequent increase in actuator travel prior to the unit reaching its end-travel (maximum extension).

Maintenance Activity (ii) was required to address one of the most significant system faults encountered. In ‘As-Found’ condition 40% of the test trailers demonstrated insufficient (or indeed virtually no) brake application force. This was due to the brake actuator (ram) travel having increased over time (to compensate for brake lining wear) until the ram end-travel was reached (~75 mm ram extension - see Figure 5.6).

At this point further (limited) brake lining wear causes braking effort to reduce dramatically, effectively rendering the service braking system inoperative. Lack of brake shoe application force results in glazing of the friction linings (see Figure 5.5) and corrosion of the drum braking surface (see Figure 5.6). On the plus side, under these circumstances the trailer brake
Figure 5.5 Reasons for poor service brake performance (1)

(i) Glazed brake linings due to rams reaching end-travel and failing to apply sufficient pressure to brake shoes (left);
(ii) Lack of regular maintenance, system adjustment and ingress of foreign matter (middle & right)

- shoes do not suffer further wear, simply because they are no longer doing any work. Instead all braking effort and consequent wear becomes the responsibility of the tractor’s braking system which, being overloaded, then suffers rapid wear and eventually fails prematurely.

It is worthy of note that, despite the fact that very few of the test trailers / trailed appliances exhibited any evidence to regular / any maintenance, not a single instance of excessively-worn friction linings was encountered during the study. The above scenario explains this conundrum.

The immediate solution to this problem is part-practical and part-educational. The practical solution (see Section 2.3) concerns the selection (or installation during upgrade) of brake lever arms incorporating manual, screw-type, slack adjusters. As drum brake friction linings wear the brake actuator travel (or ‘slack’) will increase. Most hydraulic or pneumatic brake actuators have a stroke of approx. 75 mm / 3 inches. It is a very simple matter to measure the actual stroke of a trailer’s brake rams, albeit following a safe system of work (e.g. having previously applied the tractor’s parking brake and chocked all the wheels of the tractor-trailer combination). If the ram stroke exceeds ⅔ max. travel (i.e. 50 mm / 2 inches) then slack adjustment is required, otherwise ram end-travel will soon be encountered, possibly whilst on-road with regrettable consequences.

This all sounds fine in theory, but simple splined brake lever arms are difficult to adjust under favourable conditions, let alone when corroded following many years service. In contrast adjustment of the screw-type slack adjusters (see Figure 2.4) is simple, quick and convenient: their presence therefore greatly increases the likelihood that adjustment will actually be made. A simple component costing less than £20, but one which could result in a trailer’s braking system maintaining its effectiveness in-service ! Higher specification trailer axles tend to feature manual slack adjusters as standard equipment.

Regarding education, it is fair to ask how many tractor drivers have received any form of training or instruction relating to the subject of trailer braking? There answer remains unknown. Trailers are often regarded as simple, everyday machines, so an instruction manual supplied by the manufacturer may well not be consulted. Hopefully, many users will read this report, become more aware of the issues involved and seek to make improvements.
Figure 5.6  Reasons for poor service braking performance (2)
(Brake rams reaching end-travel due to lack of lever arm adjustment: brake drum corruption due to subsequent absence of brake shoe contact)

An alternative approach, arguably worthy of applause, is employed on trailers made by Richard Larrington Ltd (see Figure 5.7). A simple instruction plate is placed on the front corner of the chassis. In addition to general safety messages, recommended tyre pressures and fastener tightening torques, simple information is provided regarding brake slack adjustment, both in written and pictorial form. Larrington trailers feature screw-type slack adjusters, so part of the battle is already won, but surely a simple ever-present reminder to the driver whenever he/she makes the brake and tipping hose connections, must be a move in the right direction?

Figure 5.7  Larrington trailer instruction plate
5.3 UPGRADING TRAILER BRAKING SYSTEMS

The current, undesirable situation regarding trailer braking performance has, in large part, resulted from market-driven developments in the maximum road speed of ‘conventional’ agricultural tractors. As discussed in Section 1, most UK agricultural trailers are fitted with braking systems designed to operate within the 20 mph (32 km/h) UK maximum speed limit for un-suspended vehicles, as specified by the Road Vehicles (Construction and Use) Regulations (Statutory Instruments, 1986). However, virtually all UK tractors sold since 1995 have 25 mph (40 km/h) maximum speed capability and many modern ‘conventional’ tractors sold since 2005 are capable of 30 mph (50 km/h) on-road. Whilst the braking systems of these (suspended front axle) tractors has been designed to accommodate operation at these speeds, upon reaching UK farms the vehicles are frequently hitched to existing trailers which, as this investigation categorically shows, struggle to meet statutory braking performance requirements for 20 mph / 32 km/h operation, let alone anything faster.

As previously discussed (see Section 1), if the performance of a trailer’s braking system is below-par, the additional braking load is automatically transferred to the towing vehicle. A tractor’s braking system is over-sized by design, in order to accommodate the mass of attached (mounted) implements, but it is totally unrealistic to repeatedly expect the tractor’s brakes to dissipate surplus kinetic energy resulting from decelerating an under-braked (and typically over-loaded) trailer. In some respects the industry has been complacent regarding an entirely predictable issue. As indicated by Figure 5.8, taking 20 mph max. speed operation as a baseline, operation at 25 mph (max.) increases the energy dissipation requirement placed on a tractor and trailer’s braking systems by 56%; but travelling just 5 mph faster (30 mph) raises the energy level by 144% more than (or approx. 2.5 times) the value experienced at 20 mph. Whilst a given tractor’s braking system may have had sufficient spare capacity to deal with the (tractor and trailer) situation at 25 mph, the brake loading resulting from 30 mph operation with an inadequate contribution from the trailer’s braking system frequently proves to be one step too far!

Figure 5.8 Disproportionate effect of increasing speed upon vehicle kinetic energy (braking system load)
However, it would be entirely false to suggest that trailers (and braking systems) suitable for higher speed operation are not readily available from most UK trailer manufacturers, often in the form of optional equipment for standard models. But some industry observers have noted that such higher-spec. models often carry a disproportionate financial loading which, combined with the inherent cost-sensitivity of the agricultural marketplace, has regrettably limited their appeal and consequent sales. As a further twist, in the main, prospective purchasers do not readily appreciate that, once purchased, the overall running and indeed the individual component parts costs of such higher spec. (commercial-type) trailer axles and braking systems are significantly lower than those of conventional agricultural-spec. units.

A significant part of the problem stems from the fact that the frontline operational life of an agricultural trailer (~15-25 years or more) typically outlasts 2 or 3 replacement tractors. It is therefore inevitable that the specification of the UK trailer fleet will lag that of tractors, particularly if the latter experiences a period of rapid, market-driven development. But if when selecting a replacement trailer / trailed appliance, a lower (20 mph) specification unit is chosen for (illegal) use behind 25 and 30 mph tractors, has the owner got anyone but himself to blame should the least problems he experiences be excessive wear and premature failure of the tractors’ braking systems and is subsequently presented with a £2000 – 3000 repair bill by his dealer? Given the costs of higher specification trailer brakes, many would observe that this scenario makes poor economic sense (see Section 5.4).

So to upgrade an existing trailer, to purchase a higher-spec. replacement or to do nothing, that is the question! Except in instances of extremely prominent safety issues (e.g. tractor safety cab / roll-bars), vehicle / safety legislation is very rarely retrospective and so applies only to new equipment manufactured / sold after a certain point in time. As discussed in Section 3.3, it is very likely that EC legislative requirements for agricultural trailer (and trailed appliance) braking systems will be introduced, although probably not before 2010-11. This legislation is likely to increase system performance requirements, albeit not by a dramatic or impractical degree. However, importantly, it will almost certainly introduce a requirement for Type-Approval of agricultural trailers, meaning that examples of given designs will have to demonstrate conformity with the legislation / regulations prior to sale. In other words, for the first time, any agricultural trailer’s braking system will have to show its ability to meet the (revised-EU) statutory performance levels when new. Whether such performance levels are achieved during subsequent use will then be entirely subject to the provision of adequate maintenance.

If aware of the potential problems, how can a trailer / trailed appliance owner / operator address an existing unsatisfactory situation or, alternatively, ensure a replacement vehicle is adequately specified for purpose when purchased? Detailed information regarding the need for and feasibility & likely cost of upgrading the braking systems and running gear of each of the vehicles tested is given in Appendix 2. Details of likely modifications required for safe (and generally legal) operation at maximum speeds of 20, 25 and 30 mph (32, 40 and 50 km/h) are given, together with the likely component costs. Therefore, in the first instance, the reader is advised to select the test vehicle(s) with similar features to their own specific example(s) and consider the upgrade recommendations given.

However, in broad terms, what (measured, appropriate) steps should be seriously considered by owners / operators of agricultural trailers and trailed appliances? As with so many things, it all depends upon the intended use of the vehicle, or more specifically the fundamental question “How Fast?” An overview of potential braking system modifications, their justification and necessity (with respect to maximum operating speed) is depicted by Table 5.1.
Table 5.1  General levels of trailer braking system upgrade required to permit safe and sustainable vehicle operation at common max. road speeds

<table>
<thead>
<tr>
<th>Braking System Upgrade</th>
<th>Justification / Likely Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Screw-type Brake Lever Arms</td>
<td>Assists / encourages regular braking system adjustment</td>
</tr>
<tr>
<td>(<em>manual slack adjusters</em>)</td>
<td></td>
</tr>
<tr>
<td>Increase Brake Actuator (ram) Diameter</td>
<td>Generates greater braking effort from existing foundation brakes</td>
</tr>
<tr>
<td>Increase Brake Hose Diameter</td>
<td>Improves braking system response characteristics, particularly if larger rams have been installed</td>
</tr>
</tbody>
</table>
| Install Breakaway Failsafe System      | Applies trailer brakes upon accidental separation. UK statutory requirement for operation above 20 mph  
  (*N.B.: Dual line pneumatic systems provide this function automatically*) |
| Install Load Sensing System            | Essential if increasing braking performance (by means of larger rams or foundation brakes) to prevent wheel locking and excessive tyre wear during unladen braking |
| Install Larger (*S-cam type*) Brakes   | Necessary in many cases to achieve statutory braking performance levels stipulated for operation above 20 mph.  
  (*replace axles*)  
  - Should definitely be considered if operating with 30 mph / 50 km/h tractors |

Figure 5.9 summarises the proportion of the tested trailers / trailed appliances deemed to require braking system upgrades for operation at max. road speeds of either 20, 25 or 30 mph, broken down into the specific braking system hardware categories identified in Table 5.1. Whilst it is dangerous to draw firm conclusions from such data, it will be noted that:-

- Whilst not essential for operation at 20 mph, 60% of the test vehicles would have benefitted from installation of screw-type brake lever arms (*manual slack adjusters*). This increased to 70% for operation >= 25 mph;
- A very significant proportion of vehicles required larger diameter brake actuators (60 – 100%), depending upon the intended speed of operation. Larger diameter brake hoses should accompany such modifications to maintain or improve braking system response characteristics;
- Whilst not legally required in the UK for <= 20 mph operation, 90% of the test vehicles would require installation of breakaway failsafe systems if hydraulic braking was to be used at 25 or 30 mph. (*N.B.: Vehicle No.6 already had such a system installed*);
• Whilst unnecessary for 20 mph operation, 30% of the test vehicles would benefit from addition of load sensing systems for normal operation up to 25 mph: this increased to 85% of those vehicles deemed potentially suitable (after modification) for use at 30 mph. (N.B.: The large square baler would not require load sensing due to the relatively small difference between its laden and unladen mass);

• The foundation brakes of all the test vehicles were theoretically suitable for 20 mph operation if applied with sufficient force. 10% required larger foundation brakes for 25 mph operation. 70% of the vehicles deemed potentially suitable for 30 mph operation were considered to require larger foundation brakes (i.e. replacement axles);

• 30% of the test vehicles were deemed to be unsuitable for upgrading for on-road operation at 30 mph.
5.4 ECONOMICS OF BRAKING SYSTEM UPGRADING

The question of whether or not to upgrade the braking system of an existing trailer depends partly upon practical feasibility, partly upon economic viability and, last but not least, the desire for legal compliance. The latter is an issue for the individual user / farm business to decide upon and it would be irresponsible for the author to advocate anything other than full legal compliance in all instances. Unfortunately, if the test vehicles targeted by this investigation are deemed representative of the UK trailer fleet, legal compliance would appear to be a rare occurrence. The practical feasibility of upgrading each of the test vehicles has been determined (see Appendix 2): the vehicles encompassed a sufficiently broad range of braking system and undergear designs and configurations to enable comparisons to be drawn with the majority of frontline trailers on UK farms.

The economic viability of braking system upgrading depends very much upon the starting point, namely the remaining potential service life of the vehicle and the axle / foundation brake size and type (flat or S-cam) currently fitted. This investigation has shown that, if adequately specified at purchase and subsequently well-maintained, a frontline working life of 30 years plus is not an unreasonable expectation of a well-designed trailer.

The parts-only cost of upgrading a tandem-axle vehicle already fitted with suitable axles and foundation brakes (e.g. Ø406 x 120 mm or Ø420 x 180 mm S-cam) for 30 mph operation can be as little as £500 (see Appendix 2), this activity being within the capability of a well-equipped farm workshop. Bringing trailers fitted with conventional agricultural spec. braking systems up to a standard suitable for 25 mph operation would cost ~£750 - £1000: however, further enhancement to enable trouble-free operation at 30 mph (max.) would require larger foundation brakes and therefore axle replacement, adding approx. £1500 to the (parts) bill for a tandem-axle trailer (see Appendix 3 for details of trailer axle and braking system component suppliers). These costs must be considered in relation to the value of the vehicle or, alternatively, the cost of trading-in and purchasing a replacement vehicle fitted with higher specification running gear and brakes.

Aside from legality issues, choosing to take no action regarding trailer braking systems can prove to be an even more costly option. Virtually all modern ’conventional’ tractors utilise oil-immersed brakes housed in the rear axle. The brakes frequently share their cooling oil with the tractor’s hydraulic system, relying upon efficient filtration systems to remove debris and contaminants. Overloading of the tractor’s braking system results in excessive component wear, followed eventually by premature brake failure. However this creates two further problems. Firstly, being totally enclosed components designed to last the lifetime of the vehicle under normal usage, it is not readily possible to determine if a tractor’s brakes are wearing excessively. Secondly, whilst wearing at an excessively high rate, brake friction material contaminates the tractor’s rear axle oil, placing abnormally high loads on the hydraulic filtration system.

In due course the filters will clog and, should the problem not be rectified rapidly (by taking the vehicle out of service and dismantling the rear axle to effect brake component replacement), the filters will be automatically-bypassed to maintain transmission lubrication. The contaminated oil will then begin to cause rapid wear of the extremely complex (and costly) hydraulic pumps and valves which utilise the rear axle reservoir. Depending upon vehicle design, these can include the three-point linkage and external hydraulics (remote/spool valves), the powershift transmission control system and the steering system. It is for this reason that excessive (oil-immersed) tractor brake wear can cause an great deal of collateral damage (wear) to other vehicle components, thereby greatly increasing the eventual cost of repair.
If the problem is addressed at an early stage, repair costs (parts and labour) are likely to be in the region of £1750, irrespective of vehicle make or model. Should the issue not be dealt with promptly, resulting in more widespread contamination and wear within the tractor back axle, the repair cost could easily exceed £3000 per vehicle. In the light of this information the £750 - £2500 cost of upgrading a tandem-axle trailer’s braking system to a specification which is suited to its operation, would appear to be money well-spent; especially given the fact that:

i) The running (braking system wearing parts replacement) costs of a large tandem-axle trailer fitted with commercial-spec. (‘S’ cam-type) axles and foundation brakes is likely to be in the region of £40 per annum;

ii) If overloaded again by inadequate trailer brakes, the tractor’s braking system will potentially require further, similar repair in less than 2 years.
6. CONCLUSIONS AND RECOMMENDATIONS

The conclusions of this investigation, and the recommendations which may be derived from them, cover a number of distinct but nonetheless related areas, namely:

iv) In-service performance of trailer (and trailed appliance) braking systems;

v) Choosing and using agricultural trailer brakes:
   a) Maintaining and/or upgrading existing vehicle braking systems
   b) Selection of appropriate systems on new vehicles

vi) Agricultural trailer braking legislation.

In-Service Trailer Braking System Performance

• Assuming the example trailers and trailed appliances targeted by the investigation are representative of (hydraulically-braked) vehicles in frontline service on UK farms, it would appear that in excess of 80% of such vehicles are being operated with inadequate (and illegal) service braking systems. Such shortfalls in towed vehicle braking performance are greatly increasing the braking load imposed upon the towing vehicle (tractor), significantly increasing the likelihood of excessive tractor brake wear and premature system failure;

• In ‘As-Found’ off-farm condition, 90% of the trailers / trailed appliances tested failed to meet the current UK statutory service brake performance requirement (minimum 25% braking efficiency) for 20 mph (max.) operation. Following (farm) workshop braking system maintenance, 40% of the test vehicles achieved / exceeded the statutory performance requirement and a further 20% approached the required level. Nonetheless, 40% of these modern and supposedly serviceable vehicles still failed to demonstrate adequate service brake performance;

• The parking brakes of 40% of the test vehicles were inoperative in ‘As-Found’ off-farm condition. Only one vehicle met the parking brake performance requirement stipulated by BS4639:1987 (and the proposed (draft) EU Regulations for towed agricultural vehicles), either in ‘As-Found’ or ‘Post-Maintenance’ condition;

• Inadequate maintenance was undoubtedly the primary cause of poor vehicle braking system performance in ‘As-Found’ condition. However, this was primarily due to lack of brake actuation system adjustment, rather than failure to renew worn-out components (e.g. friction linings). Nonetheless, perhaps if the actuation systems had been adjusted and had operated as intended, other system ‘consumable’ items would have exhibited a greater degree of wear. Also, it is not possible to determine whether maintenance shortfalls resulted from lack of appropriate knowledge or failure to implement adequate procedures;

• Whilst highlighting a significant absence of trailer braking system maintenance on UK farms, the ‘Post-Maintenance’ service brake performance results suggest that, in certain instances, shortfalls in vehicle braking system design and/or specification prevented compliance with UK statutory (Construction and Use) requirements;

(continued)
Choosing and Using Agricultural Trailer Brakes

• To prevent overloading of the tractor’s braking system, it is extremely important that the braking performance (efficiency) of the trailer / trailed appliance is similar or equal to that of the towing vehicle (typically 45 – 60%). Otherwise shortfalls in the trailer’s braking performance must be made up for by the tractor’s braking system, with inevitable results. Tractor-trailer stability during braking will also be compromised;

• Single-line hydraulically-actuated trailer brakes have served UK agriculture well for the last 30 years, but trailer / trailed equipment size and ‘conventional’ tractor maximum road speed have both increased to a point where a more comprehensive, higher performance trailer braking system is now required. It is possible to upgrade hydraulic trailer brakes to deliver acceptable performance and response characteristics (including breakaway failsafe functionality). Alternatively, consideration should be given to use of dual-line pneumatic braking systems;

• It is essential that a trailer’s / trailed appliance’s foundation brakes are large enough to meet the energy dissipation requirements induced by vehicle payload and, more significantly, likely maximum operating speed. The braking system load associated with stopping from 30 mph (50 km/h) is approximately 2.5 times that generated from an initial speed of 20 mph. ‘S’ cam-type brakes are preferable to the ‘flat’ cam-type at speeds above 20 mph;

• The braking performance of in-service (tandem-axle) trailers can frequently be improved at relatively limited (components) cost: typically £700 – £1300 if the existing axles and foundation brakes are suitable for the intended purpose, rising to ~£2500 if replacement axles and larger (‘S’ cam-type) foundation brakes are also required;

• The running and replacement component costs of larger (commercial) specification trailer axles and foundation brakes are frequently much lower than those of smaller, agricultural specification units, due to component commonality with other on-road vehicles;

• If contemplating purchase of a new vehicle, or upgrading an existing trailer / trailed appliance, braking system specification and design should be selected to assist and encourage regular brake adjustment and servicing, e.g. fitment of brake lever arms incorporating manual, screw-type slack adjusters. Remember a new trailer will probably outlast 2 – 3 replacement tractors (15 – 25 years plus), so invest for the future;

• If equipped with a high-specification (~50% efficiency) braking system, as required for over-20 mph operation in the UK, it is essential that a trailer incorporates a load sensing system, to avoid over-braking, wheel lock, excessive tyre wear and potential vehicle instability during unladen braking. ABS trailer brakes are also currently a UK statutory requirement for operation above 20 mph;

• In many instances the braking performance of in-service hydraulically-braked trailers and trailed appliances may be improved by increasing brake ram diameter (actuating force). However, this is not a step to be taken by the uninformed, particularly without the advice of the trailer manufacturer and/or the axle supplier. If system performance is improved by this method, the addition of a load sensing system will probably be necessary to prevent over-braking when unladen;

• It is a UK legal requirement that any towed agricultural vehicle used at speeds above 20 mph incorporates a breakaway failsafe braking system, which applies the trailer brakes upon accidental tractor-trailer separation. Retrofit electro-hydraulic systems are available for existing (single-line) hydraulically-braked vehicles, whereas dual-line pneumatic braking systems already incorporate this function. Given that virtually every tractor above 80 hp sold in the UK since 1995 is capable of 25 mph (40 km/h) maximum road speed, it is perhaps surprising that failsafe trailer braking systems are not more commonplace;
Agricultural Trailer / Trailed Appliance Braking Legislation

• At present, agricultural trailer braking regulations in the UK are arguably outdated. There is no official means of ensuring agricultural trailer braking systems are legally compliant when first sold. Once in-service, a statutory responsibility is placed upon the user to ensure the towed vehicle’s braking system is maintained and continues to perform adequately (C&U Regulation 18), albeit there is at present no convenient, recognised and readily-accessible means of quantifying trailer braking system performance levels;

• The proposed EU agricultural vehicle braking regulations will potentially serve to remove confusion regarding tractor-trailer braking, by stating clear, enhanced system performance requirements. Whilst necessitating greater braking performance, which arguably should have already been present on existing trailers used above 20 mph for UK regulatory compliance, the industry will benefit from the reduction in (or hopeful elimination of) the disparity between tractor and trailer braking performance requirements. In practise this is likely to improve vehicle combination braking and stability, enhance safety and almost certainly reduce tractor-trailer braking system repair costs;

• It is strongly-advised that current UK statutory braking performance requirements for agricultural vehicles be clarified / modified to specify:
  o The actual system actuating (line) pressure at which the stipulated (minimum) levels of service brake performance should be achieved;
  o An actual minimum value for agricultural trailer and trailed appliance parking brake performance.

• It is suggested that, either by introduction of a statutory requirement or an industry code of practice, information regarding the need for, frequency and means of brake adjustment should be clearly displayed on the vehicle chassis / body;

Possible Future Work

Given the availability of adequate resources, it is considered the following issues would benefit from further investigation in the near-future, particularly given the forthcoming introduction of EU tractor-trailer braking regulations, EC Type-Approval for agricultural trailers and trailed appliances, and the inevitably-increasing proportion of the UK tractor fleet which will have 30 mph (50 km/h) maximum road speed capability. Many questions as yet remain unanswered, including:

• The adequacy of performance of (pneumatic and/or hydraulic) load sensing braking systems available for agricultural trailers and the steps necessary to redress any possible system shortfalls;

• The response characteristics of hydraulic trailer braking systems. Can they meet the performance levels likely to be stipulated by EU tractor-trailer braking regulations? What modifications would be necessary to enable existing system designs to do so?

• Hydraulic trailer braking systems have served UK agriculture well. They are still permitted by the (draft) EU regulations, albeit in enhanced format. Can hydraulic trailer braking systems meet these requirements and, if so, in what form? If not, is it appropriate to encourage a wholesale conversion to pneumatic trailer braking systems in the UK?
7. REFERENCES


APPENDICES

APPENDIX 1: TEST TRAILER MAINTENANCE RECORD SHEET

<table>
<thead>
<tr>
<th>TRAILER MAKE:</th>
<th>DATE BUILT:</th>
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<tbody>
<tr>
<td>TYPE (e.g tandem-axle tipper):</td>
<td></td>
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<tr>
<td>SERVICE DATE(S):</td>
<td>SPRUNG DRAWBAR? YES / NO</td>
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<tr>
<td>SUSPENSION TYPE:</td>
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<tr>
<td>AXLE MAKE &amp; SIZE:</td>
<td>BRAKE HOSE DIAMETER:</td>
</tr>
<tr>
<td>BRAKE SIZE (drum diameter &amp; shoe width):</td>
<td></td>
</tr>
<tr>
<td>TYRE SIZE &amp; MAKE:</td>
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<tr>
<td>HANDBRAKE TYPE:</td>
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### FRONT NEARSIDE

<table>
<thead>
<tr>
<th>Brake Lining Thickness (mm):</th>
<th>Front Edge</th>
<th>Rear Edge</th>
<th>Brake Lining Thickness (mm):</th>
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<th>Rear Edge</th>
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<tbody>
<tr>
<td>Top Shoe =</td>
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<td>Top Shoe =</td>
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<tr>
<td>Btm Shoe =</td>
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<td>Btm Shoe =</td>
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### FRONT OFFSIDE

<table>
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<tr>
<th>Brake Actuator Travel (mm):</th>
<th>Before adjustment =</th>
<th>After adjustment =</th>
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<tr>
<th>Comments / Faults Repaired</th>
<th>Comments / Faults Repaired</th>
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<td></td>
<td>REAR NEARSIDE</td>
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<td>---------------------------------------------------</td>
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<tr>
<td>Brake Lining Thickness (mm):</td>
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<tr>
<td></td>
<td>Front Edge</td>
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<tr>
<td>Top Shoe =</td>
<td>............</td>
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<tr>
<td>Btm Shoe =</td>
<td>............</td>
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<tr>
<td>Brake Actuator Travel (mm):</td>
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<td>Before adjustment =</td>
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<tr>
<td>After adjustment =</td>
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<tr>
<td>Comments / Faults Repaired</td>
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<tr>
<td>HANDBRAKE SERVICING REQUIRED:</td>
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</tbody>
</table>
APPENDIX 2: TRAILER BRAKING PERFORMANCE ASSESSMENT - RESULTS

APPENDIX 2.1: VEHICLE No.1 – 14 TONNE TANDEM-AXLE GRAIN TRAILER - 1999

A2.1.1 Specification and Condition

Type: Tandem-axle grain trailer
Nominal capacity: 14 tonnes
Body volume: ~18 m³
Year of manufacture: 1999
Age at time of test: 9 years
Axle Suspension: Mono-leaf springs plus trailing arms
Drawbar Suspension: Multi-leaf spring
Axle type: ADR 10-stud – 90 mm square
Service Brake system: Single-line hydraulic
Brake size / type: Ø 400 mm x 80 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 25 mm x 75 mm stroke
No. of Rams per axle: 2
Brake hose diameter: ½”
Brake Lever Arm: Splined-type retained by clamp bolt
Operating radius: 150 mm
Parking Brake system: Cable-operated – Lever & quadrant-type on front axle only
Bogie wheelbase: 1.35 m
Wheel track: 1.8 m
Tyre size: 15 R 22.5 18PR (commercial)
Tyre pressure: ~ 4.0 bar

General Condition:- One of a fleet of six frontline ~14 tonne trailers from a large (2000 ha) East Anglian mixed farming estate. Used for grain, manure, sugar beet & other general bulk material transport. In serviceable condition, exhibiting signs both of recent intensive use and some maintenance ‘as-found’ (off-farm).

Table A2.1.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>3000</td>
<td>7600</td>
<td>7600</td>
<td>18,200</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>670</td>
<td>1,730</td>
<td>1,950</td>
<td>4,350</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>2,820</td>
<td>7,540</td>
<td>7,880</td>
<td>18,240</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,850</td>
<td>7,390</td>
<td>7,560</td>
<td>17,800</td>
</tr>
</tbody>
</table>
A2.1.2 Braking System Maintenance – Comments

- Vehicle service braking system generally found to be in quite good condition, merely requiring cleaning, adjustment and appropriate lubrication;
- (Bonded) brake shoes had good thickness of friction lining remaining (6.5 – 7.5 mm: probably no more than 8 mm when new). Brake drums were not scored. One brake shoe backplate pivot bolt required tightening;
- Main maintenance activity concerned adjustment (reduction) of brake ram travel (with the service brakes fully applied) from ~60 mm ‘As-Found’ to ~37 mm ‘Post-Maintenance’. This was achieved firstly by relocating each brake lever arm to a new annular spline on the brake camshaft, and thereafter by fine adjustment of brake ram adjuster nut(s) (see Figure A2.1.1). It is important to ensure that, following adjustment, the brake shoes do not drag when the brakes are released. This restriction limited the extent of ram travel reduction to ~37 mm (~50% of max travel);
- The parking brake lever was initially found to have excess travel, but adjustment of brake lever arm travel (see above) also addressed this issue.

A2.1.3 Braking System Performance

Service Brake
(see Figure A2.1.2)

Trailer No.1 achieved a reasonable level of performance in ‘As-Found’ condition, but fell short of current UK statutory / BS 4639:1987 requirements. Nonetheless, it demonstrated a strong, linear increase in braking efficiency with respect to line pressure, indicating that the system was not being compromised by the brake actuating rams reaching end travel;

‘Post-Maintenance’ performance was substantially better, comfortably exceeding UK service brake performance requirements for ≤ 20 mph agricultural trailer operation.
Parking Brake
(see Figure A2.1.3)

Parking brake performance in ‘As-Found’ condition was poor, primarily due to excess brake actuation system travel. Adjustment of the system during maintenance addressed this issue (see Appendix 2.1.2) and resulted in a 69% increase in system performance. Unfortunately even this only represented 45% of the performance requirement stipulated by BS 4639:1987 and current draft EC tractor-trailer braking regulations.

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**Figure A2.1.2** Trailer No.1 service brake performance test results
(arrow denotes UK statutory performance level: < 25% efficiency at 100 bar)

**Figure A2.1.3** Trailer No.1 parking brake performance test results
A2.1.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:-** Acceptable: braking system meets UK statutory requirements;

- **25 mph / 40 km/h:-** ‘Officially’ illegal in the strictest sense, but braking performance such that the vehicle could be made acceptable ‘technically’ if a hydraulic breakaway failsafe system were added and brake servicing frequency increased (to 6 monthly). Fitting replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment;

- **30 mph / 50 km/h:-** Ø400 x 80 mm flat-cam brakes are unsuitable for higher-speed operation (performance inadequate and control poor). Install replacement axles with larger S-cam type brakes (e.g. Ø406 x 120 mm or Ø420 x 180 mm), appropriate diameter brake rams and lever arms incorporating screw-type slack adjusters. Fit hydraulic breakaway failsafe system plus load sensing system to compensate for increased braking performance (when unladen). Install larger diameter (½”) hydraulic brake hoses to improve system reaction time.

Parking Brake:- Inadequate performance. Means of application and (possibly) number of axles braked require revision.

Cost / Feasibility of Upgrade

- Trailer body and chassis are in good condition and capable of further 10 – 15 years frontline use. Potentially worthy of investment;

- Existing mono-leaf spring suspension already features trailing arms which are potentially capable of accommodating likely increased braking torques, but consult trailer manufacturer for confirmation.

Likely Costs:

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Replacement lever arms (incl. manual slack adjusters)</td>
<td>£60</td>
</tr>
<tr>
<td>ii) Hydraulic breakaway failsafe system</td>
<td>£350 - 400</td>
</tr>
<tr>
<td>iii) Hydraulic load sensing</td>
<td>£300 - 350</td>
</tr>
<tr>
<td>iv) Larger (½”) diameter hydraulic brake hoses</td>
<td>£100</td>
</tr>
<tr>
<td>v) Replacement brake rams (possibly)</td>
<td>£115</td>
</tr>
<tr>
<td>vi) Replacement axles featuring larger brakes (2 OFF)</td>
<td>£1400 - 1600</td>
</tr>
</tbody>
</table>

**Total** = **£2325 - 2625**
APPENDIX 2.2: VEHICLE No.2 – 14 TONNE TANDEM-AXLE GRAIN TRAILER - 2001

A2.2.1 Specification and Condition

- **Type:** Tandem-axle grain trailer
- **Nominal capacity:** 14 tonnes
- **Body volume:** ~20.5 m³ (0.25 m side extension)
- **Year of manufacture:** 2001
- **Age at time of test:** 7 years
- **Axle Suspension:** Multi-leaf springs
- **Drawbar Suspension:** Multi-leaf spring
- **Axle type:** ADR 8-stud – 90 mm square
- **Service Brake system:** Single-line hydraulic
- **Brake size / type:** Ø 400 mm x 80 mm wide drum - flat cam (agricultural)
- **Brake Ram:** Ø 20 mm x 75 mm stroke
- **No. of Rams per axle:** 2
- **Brake hose diameter:** ¼”
- **Brake Lever Arm:** Splined-type retained by clamp bolt
- **Operating radius:** 150 mm
- **Parking Brake system:** Cable-operated – Multiple-pull ratchet-type on front axle only
- **Bogie wheelbase:** 1.3 m
- **Wheel track:** 1.85 m
- **Tyre size:** 18.5 R 22.5 20PR (commercial)
- **Tyre pressure:** ~ 5.5 bar
- **General Condition:**
  Primary frontline grain trailer from a 400 ha East Anglian arable farm. Used exclusively for grain transport. 0.25 m high side extensions professionally installed to increase capacity. In good condition, exhibiting little apparent wear, but no signs of recent maintenance ‘as-found’ (off-farm). Owner commented that braking performance had deteriorated since purchase (second-hand) 2 years ago.

### Table A2.2.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>3,500</td>
<td>8,000</td>
<td>8,000</td>
<td>18,220</td>
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<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>770</td>
<td>2,340</td>
<td>2,020</td>
<td>5,130</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>3,020</td>
<td>7,980</td>
<td>7,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,730</td>
<td>8,140</td>
<td>7,620</td>
<td>18,490</td>
</tr>
</tbody>
</table>
**A2.2.2 Braking System Maintenance – Comments**

- Although fully-operational (in terms of actuator movement), the service braking system was found to be in extreme need of adjustment and appropriate lubrication;

- The most critical area concerned reduction of brake ram travel (to ~30 mm) to restore service brake functionality. ‘As-Found’, with the service brakes fully-applied, brake ram travel was ~70 mm and ~76 mm for the front and rear axles, respectively (see Figure A2.2.1). Given that typical max. travel is ~76 mm, these rams had either reached or were about to reach their end-travel, from which point no further force could be applied to the brake shoes. To redress this problem the brake lever arms were repositioned on the camshaft splines, final adjustment of travel being made via the brake ram adjuster nut(s);

- Brake shoes had good thickness of friction material remaining (6.5 – 7.5 mm: probably no more than 8 mm when new). Further brake lining wear had not occurred due to the inability of the actuators to apply full force to the brake shoes, the former having reached the end of their available travel. Some light scoring and corrosion was present on the brake drum wearing surfaces, but this was insufficient to warrant replacement. Other than general cleaning and lubrication, the service brakes required no further attention;

- The parking brake control (multi-pull ratchet-type) was initially found to be seized. Freeing-off and appropriate lubrication restored its functionality, but only to within the performance limitations imposed by the system design (similar to other test trailers).

**A2.2.3 Braking System Performance**

*Service Brake*

(see Figure A2.2.2)

In ‘As-Found’ condition Trailer No.2 demonstrated a very poor level of braking performance, substantially below statutory requirements. The extremely limited increase in braking efficiency with line pressure indicated that higher system pressures were not being translated into greater braking effort, either due either to faults in the force transmission system or the foundation brake (drum / shoes). Subsequent maintenance showed it to be the former.
Following fault rectification, ‘Post-Maintenance’ braking performance improved considerably, demonstrating a much better increase with line pressure. However, regrettably, the vehicle was still unable to quite meet UK statutory performance requirements. This may seem strange when compared with the performance of Trailer No.1 of (approx.) equivalent carrying capacity and identical foundation brake size (Ø 400 mm x 80 mm) and brake lever arm length (150 mm). The 28% lower braking efficiency generated by Trailer No.2 was no doubt affected adversely by the slightly larger (+3.8%) radius tyres fitted. However, the primary cause for this disparity was the installation of smaller diameter brake actuating rams (Ø 20 mm in lieu of Ø 25 mm on Trailer No.1), the force generation capability of the former units being 36% lower.

**Parking Brake**

(see Figure A2.2.3)

Parking brake performance in ‘As-Found’ condition was poor, primarily due to lack of maintenance and excess brake actuation system travel. System maintenance and adjustment (see Appendix 2.2.2) resulted in a 200% increase in system performance. Unfortunately even this only represented 49% of the performance requirement stipulated by BS 4639:1987 and current draft EC tractor-trailer braking regulations.
A2.2.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:** Currently fails to meet UK statutory requirements. Installation of Ø 25 mm brake rams would probably increase braking performance to acceptable levels. Larger diameter (½") hydraulic brake hoses would also be beneficial;

- **25 mph / 40 km/h:** Unsuitable in present form, but if modified as above (installation of Ø 25 mm brake rams) plus addition of an hydraulic breakaway failsafe system, the vehicle would be acceptable ‘technically’, if still illegal in the strictest sense. Would also be necessary to increase brake servicing frequency (to 6 monthly). Fitting replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment;

- **30 mph / 50 km/h:** Totally unacceptable in current state. Requires larger S-cam type brakes (e.g. Ø406 x 120 mm or Ø420 x 180 mm), appropriate diameter brake rams and lever arms incorporating screw-type slack adjusters. Also fit hydraulic breakaway failsafe system plus load sensing system to compensate for increased braking performance (when unladen). Install larger diameter (½") hydraulic brake hoses to improve system reaction time.

**Parking Brake:** Inadequate performance. Means of application and (possibly) number of axles braked require revision.
Cost / Feasibility of Upgrade

- Trailer body and chassis are in very good condition and capable of further 15+ years frontline use. Very probably worthy of investment;
- Existing multi-leaf spring suspension are acceptable for 20 – 25 mph operation, but may require addition of trailing arms to withstand increased braking torque arising from larger brakes needed for higher speed operation. Consult trailer manufacturer for guidance.

**Likely Costs:**

1. Larger (Ø 25 mm) brake rams £115
2. Replacement lever arms (incl. manual slack adjusters) £60
3. Hydraulic breakaway failsafe system £350 - 400
4. Hydraulic load sensing £300 - 350
5. Larger (½”) diameter hydraulic brake hoses £100
6. Replacement axles featuring larger brakes (2 OFF) £1400 - 1600

**Total = £2325 - 2625**
APPENDIX 2.3: VEHICLE No.3 – 14 TONNE TANDEM-AXLE GRAIN TRAILER - 1987

A2.3.1 Specification and Condition

Type: Tandem-axle grain trailer
Nominal capacity: 14 tonnes
Body volume: ~20 m³
Year of manufacture: 1987
Age at time of test: 21 years

Axle Suspension: Mono-leaf springs plus trailing arms
Drawbar Suspension: Multi-leaf spring
Axle type: FAD 8-stud – 80 mm square

Service Brake system: Single-line hydraulic
Brake size / type: Ø 300 mm x 90 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 20 mm x 75 mm stroke
No. of Rams per axle: 2
Brake hose diameter: ⅜”
Brake Lever Arm: Splined-type retained by clamp bolt Operating radius: 125 mm

Parking Brake system: Cable-operated – Lever & quadrant-type on front axle only
Bogie wheelbase: 1.35 m Wheel track: 1.75 m
Tyre size: 18 - 19.5 16PR (agricultural) Static Loaded Radius (measured) 0.525 m
Tyre pressure: Not recorded, but acceptable sidewall deflection when laden

General Condition:- Oldest of a fleet of six frontline ~14 tonne bulk trailers from a large (2000 ha) East Anglian mixed farming estate. Now used primarily for harvest-time grain transport. In good condition for age, exhibiting moderate wear, but some signs of maintenance (e.g. tyre & suspension component replacement) ‘as-found’ (off-farm).

Table A2.3.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>3000</td>
<td>8000</td>
<td>8000</td>
<td>18,000</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>800</td>
<td>1,720</td>
<td>1,870</td>
<td>4,390</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>2,960</td>
<td>7,650</td>
<td>7,560</td>
<td>18,170</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,600</td>
<td>7,480</td>
<td>7,470</td>
<td>17,550</td>
</tr>
</tbody>
</table>
A2.3.2 Braking System Maintenance – Comments

- Although apparently fully-operational (in terms of actuator movement), the service braking system was found to be in need of maintenance and adjustment, system wear having caused front axle brake ram travel to increase until the ram end-stops were reached, rendering the brakes ineffective;

- Whilst brake shoe friction lining thickness was acceptable (6 – 7 mm), some friction surfaces were glazed, others exhibited lateral scoring (perhaps the result of previous attempts to restore braking performance?). Certain areas of the brake linings were flaking and breaking up. Consequently, all brake shoes were removed, professionally-re-lined and refitted;

- As with previous test vehicles, it was necessary to reposition the brake lever arms on the camshaft splines in order to reduce brake ram travel (to ~30 mm) and restore service brake functionality (see Figure A2.3.1). No other means of secondary / fine adjustment was provided;

- The parking brake control cable snapped when first used and the cable pulley was found to be seized on its pivot. Following pulley lubrication and cable replacement, no further problems were encountered.
A2.3.3 Braking System Performance

Service Brake

(see Figure A2.3.2)

In ‘As-Found’ condition Trailer No.3 demonstrated a very poor level of braking performance, substantially below UK statutory requirements. The limited increase in braking efficiency with line pressure indicated that higher system pressures were not being translated into greater braking effort, either due to faults in the force transmission system or the foundation brake (drum / shoes). Subsequent maintenance showed there were issues with both.

Following fault rectification, ‘Post-Maintenance’ braking performance improved, demonstrating a much stronger increase with line pressure. However, regrettably, the vehicle still fell far short of UK statutory performance requirements for <= 20 mph agricultural trailers. Given the level of maintenance undertaken (brake shoe replacement, ram travel adjustment, system lubrication) one can be forgiven for questioning this inadequate performance. However, industry-recognised service brake performance calculations served to confirm the experimental results obtained. It would therefore seem that the results obtained are indeed a true reflection of the service braking system’s capabilities and these are indeed incapable of meeting current statutory performance requirements.

Parking Brake

(see Figure A2.3.3)

Parking brake performance in ‘As-Found’ condition was poor, due to the maintenance-related issues stated in Appendix 2.3.2. System overhaul and adjustment resulted in a 35% increase in system performance. Unfortunately this only represented 26% of the performance requirement stipulated by BS 4639:1987 and current draft EC tractor-trailer braking regulations and so was still woefully inadequate.
A2.3.4 Need for (and Feasibility of) Braking System Upgrade

**Suitability of braking system for operation at maximum speeds of :-**

- **20 mph / 32 km/h:-** Currently fails to meet UK statutory (C&U) requirements. Installation of Ø 25 mm brake rams and use of larger (~170 – 180 mm) lever arm radius would increase braking performance to acceptable levels.

- **25 mph / 40 km/h:-** Unsuitable in present form, but if modified as above (installation of Ø 25 mm brake rams) plus addition of an hydraulic breakaway failsafe system, the vehicle would be acceptable ‘technically’, if still illegal in the strictest sense. Would also be necessary to increase brake servicing frequency (to 6 monthly). Fitting replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment;

- **30 mph / 50 km/h:-** Unsuitable in current form. Requires larger S-cam type brakes (e.g. Ø406 x 120 mm or Ø420 x 180 mm) and appropriate diameter brake rams and screw-type brake lever arms. Also fit hydraulic breakaway failsafe system plus load sensing system to compensate for increased braking performance (when unladen). Install larger diameter (½”) hydraulic brake hoses to improve system reaction time. Suitability of tyres and existing suspension system for operation at these higher speeds is also open to question.

**Parking Brake:-**

Inadequate performance. Means of application and (possibly) number of axle braked require revision.

---

**Figure A2.3.3** Trailer No.3 parking brake performance test results
Cost / Feasibility of Upgrade

- Trailer body and chassis are in very good condition, but of slightly outdated design (21 years old). Vehicle capable of further 10 - 15 years frontline use if axles, undergear and braking system are upgraded;
- Existing mono-leaf spring suspension is possibly inadequate for operation at speeds above 25 mph / 40 km/h. Consult trailer manufacturer for guidance.

Likely Costs:

i) Larger (Ø 25 mm) brake rams £100  
ii) Replacement lever arms (incl. manual slack adjusters) £60  
iii) Hydraulic breakaway failsafe system £350 - 400  
iv) Hydraulic load sensing £300 - 350  
v) Larger (½”) diameter hydraulic brake hoses £100  
vi) Replacement axles featuring larger brakes £1400 - 1600  

Total = £2310 - 2610
APPENDIX 2.4: VEHICLE No.4 – 16 TONNE TANDEM-AXLE GRAIN TRAILER - 2007

A2.4.1 Specification and Condition

- **Type:** Tandem-axle grain trailer
- **Nominal capacity:** 14/18 tonnes
- **Body volume:** ~22 m³
- **Year of manufacture:** 2007
- **Age at time of test:** 3 months
- **Axle Suspension:** Mono-leaf springs plus trailing arms
- **Drawbar Suspension:** Multi-leaf spring
- **Axle type:** ADR 10-stud – Ø 127 mm
- **Service Brake system:** Single-line hydraulic plus dual-line pneumatic
- **Brake size / type:** Ø 420 mm x 180 mm wide drum – S-cam (commercial)
- **Brake Ram:** Combined Ø 25 mm x 75 mm stroke hydraulic ram & pneumatic actuator
- **No. of Rams per axle:** 2
- **Brake hose diameter:** ⅜”
- **Brake Lever Arm:** Manual screw-type slack adjuster
- **Operating radius:** 203 mm (front axle) 178 mm (rear axle)
- **Parking Brake system:** Cable-operated – Multi-pull ratchet-type on front axle only
- **Bogie wheelbase:** 1.35 m
- **Wheel track:** 2.00 m
- **Tyre size:** 560/60 R22.5 (flotation)
- **Tyre pressure:** 3.0 bar
- **General Condition:** Relatively new addition to the trailer hire fleet of a major East Anglian agricultural engineering dealership. One of a number of identical trailers hired primarily for bulk transportation of agricultural commodities (combinable crops, sugar beet) & by-products. Had been subject to some on-farm use, but generally in ‘as-new’ condition.

### Table A2.4.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>5,500</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>3,500</td>
<td>9000</td>
<td>9000</td>
<td>21,500</td>
</tr>
<tr>
<td>Max. Laden Mass (manufacturer’s plate)</td>
<td>3,500</td>
<td>10,000</td>
<td>10,000</td>
<td>23,500</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>670</td>
<td>2,550</td>
<td>2,630</td>
<td>5,850</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>2,630</td>
<td>8,770</td>
<td>9,300</td>
<td>20,700</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,630</td>
<td>8,770</td>
<td>9,300</td>
<td>20,700</td>
</tr>
</tbody>
</table>
A2.4.2 Braking System Maintenance – Comments

- Having only seen 3 months use since manufacture, Trailer No.4 was virtually in ‘as-new’ condition at the time of testing. The commercial vehicle - type (Ø 420 x 180 mm) foundation brakes fitted featured inspection plugs within the back-plates, thereby enabling brake lining thickness to be assessed without the need for wheel and brake drum removal. As expected, lining thickness was virtually as new;

- The trailer was fitted with both single-line hydraulic and dual-line pneumatic braking systems, although only the former’s performance was evaluated. Brake ram travel (with the service brakes fully applied) was found to be within acceptable limits (~45 - 53 mm) and required no adjustment. However, as the vehicle was fitted with external screw-type lever arm slack adjusters, any such adjustments would have been a simple and relatively quick matter;

A2.4.3 Braking System Performance

Service Brake
(see Figure A2.4.2)

As no actual maintenance was performed on the braking system of Trailer No.4, only ‘As-Found’ performance results are presented. However, this data is actually derived from two separate evaluations of the vehicle’s service braking system performance. In light of this, the degree of agreement between the data is encouraging.

It will be seen from Figure A2.4.2 that, in terms of braking efficiency, the performance of Trailer No.4’s service braking system significantly exceeds current UK statutory performance requirements for 20 mph agricultural tractor-trailer operation and (at higher operating pressures) approaches the level required for higher speed (≤40 mph) operation. As such the system is arguably well-matched to the vehicle.
Parking Brake

As discussed previously in Appendix 2.4.2, no maintenance was found to be required by either the service or parking brake systems of Trailer No.4, these being in ‘as-new’ condition. However, in contrast to that of the service brake system, parking brake performance in ‘As-Found’ condition was unspectacular. Despite correct adjustment the system was only capable of generating 35% of the performance requirement stipulated by BS 4639:1987 and current draft EU tractor-trailer braking regulations.
A2.4.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:-** Comfortably exceeds current UK statutory requirements;

- **25 mph / 40 km/h:-** ‘Officially’ not suitable in present form (with single-line hydraulic braking), but if modified by addition of a hydraulic breakaway failsafe system (*already present on the pneumatic system*), the vehicle would be acceptable ‘technically’, if still illegal in the strictest sense;

- **30 mph / 50 km/h:-** Above modifications plus addition of load sensing to both hydraulic and pneumatic systems, and increasing brake actuator size (Ø 35 mm hydraulic ram & 178 mm lever arm radius) to achieve the >= 50% braking efficiency required when laden (*brake actuators are currently undersized to avoid wheel locking when unladen*). Install larger diameter (½”) hydraulic brake hoses to improve system reaction time. Foundation brakes, axles and undergear are all suitable for higher speed use.

**Parking Brake:** Inadequate performance. Means of application and (possibly) number of axle braked require revision.

**Cost / Feasibility of Upgrade**

- Trailer body and chassis are in as-new condition. Proposed modifications involve simple exchange and/or addition of easily-accessible low-cost components;

- Vehicle should have a service life of 25 - 30 years if well cared for. However, still requires regular servicing (every 6 months).

**Likely Costs:**

1. Larger (‘dual-supply’ hydraulic/pneumatic) brake actuators £265
2. Larger (½”) diameter hydraulic brake hoses £100
3. Hydraulic breakaway failsafe system £350 - 400
4. Hydraulic load sensing £300 - 350
5. Pneumatic load sensing £200

**Total = £1215 - 1315**
APPENDIX 2.5:- VEHICLE No.5 – 12 TONNE TANDEM-AXLE GRAIN TRAILER - 1991

A2.5.1 Specification and Condition

| Type: | Tandem-axle grain trailer |
| Nominal capacity: | 12 tonnes |
| Body volume: | ~21 m³ (0.35 m side extension) |
| Year of manufacture: | 1991 |
| Age at time of test: | 17 years |
| Axle Suspension: | Mono-leaf springs plus trailing arms |
| Drawbar Suspension: | None |
| Axle type: | ROR 10-stud – Ø 127 mm |
| Service Brake system: | Single-line hydraulic |
| Brake size / type: | Ø 420 mm x 180 mm wide drum – S-cam (commercial - reconditioned) |
| Brake Ram: | Ø 20 mm x 75 mm stroke |
| No. of Rams per axle: | 2 |
| Brake hose diameter: | ¼” |
| Brake Lever Arm: | Manual screw-type slack adjuster |
| Parking Brake system: | Cable-operated – Multi-pull ratchet-type on front axle only |
| Bogie wheelbase: | 1.35 m |
| Wheel track: | 1.80 m |
| Tyre size: | 560/40 R22.5 (flotation) |
| Tyre pressure: | 3.0 bar |
| General Condition: | Primary frontline grain trailer from a 600 ha East Anglian arable farm. Used exclusively for grain transport. 0.35 m high side extensions professionally-installed to increase capacity well beyond rated ability. In good condition for age, but exhibiting signs of previous repair (although not to undergear or braking system). |

Table A2.5.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>2000</td>
<td>7000</td>
<td>7000</td>
<td>16,000</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>670</td>
<td>1,080</td>
<td>2,200</td>
<td>3,950</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>2,590</td>
<td>5,890</td>
<td>7,780</td>
<td>16,260</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,580</td>
<td>6,130</td>
<td>8,110</td>
<td>16,820</td>
</tr>
</tbody>
</table>
A2.5.2 Braking System Maintenance - Comments

- Vehicle service braking system found to be in acceptable mechanical condition, but required thorough cleaning, adjustment and appropriate lubrication. Substantial harvest debris, cobwebs and dust present within brake drum interiors (see Figure A2.5.1);
- Brake shoe friction lining thickness was entirely acceptable (8.5 – 11.5 mm; 5 mm minimum). Some slight glazing found and rectified;
- Brake ram travel beginning to reach limits of acceptability (~ 60 – 65 mm), but easily addressed by adjustment of external screw-type slack adjusters incorporated in brake lever arms (see Figure A2.5.1);
- Parking brake mechanism required no attention other than routine lubrication.

A2.5.3 Braking System Performance

Service Brake

(see Figure A2.5.2)

In ‘As-Found’ condition Trailer No.5 demonstrated inadequate braking performance, developing only 60% of the UK statutory requirement. However, the strong increase in braking efficiency with line pressure demonstrated that higher system pressures were being translated into greater braking effort, suggesting few faults within the force transmission system or the foundation brakes (drums / shoes). Subsequent maintenance showed there were certain issues with both.

Following system cleaning, lubrication and adjustment’, (‘Post-Maintenance’) performance improved substantially, demonstrating a greater rate of braking effort increase with line pressure and generally higher efficiency values, commensurate with the foundation brake size fitted to the vehicle. In this state the vehicle marginally-exceeded the UK statutory performance requirements for <= 20 mph agricultural trailers, but without a significant margin to accommodate system performance degradation in future service.
Parking Brake

(Parking Brake) (see Figure A2.5.3)

Parking brake performance of Trailer No.5 in ‘As-Found’ condition was poor. However, whilst this was due in part to the maintenance-related issues, poor system design (cable routing) served to reduce the efficiency of force transfer from the control lever to the brake lever arms (see Figure A2.5.1). Consequently, whilst lubrication and maintenance increased system performance by 25%, this still only represented 19% of the performance requirement stipulated by BS 4639:1987. A woefully inadequate and surprising result, given the vehicle’s moderate carrying capacity and substantial foundation brake size.

Figure A2.5.2  Trailer No.5 service brake performance test results
(arrows denote UK statutory performance level: - 25% efficiency at 100 bar)

Figure A2.5.3  Trailer No.5 parking brake performance test results
A2.5.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:-** Service braking system performance acceptable (just!), but no margin for likely performance reduction during service;

- **25 mph / 40 km/h:-** Unsuitable in present form. Axles, foundation brakes and suspension / undergear all suitable for use at this speed, but installation of larger diameter (e.g. Ø 25 mm) brake rams necessary to increase braking performance to acceptable levels. Hydraulic load sensing would then be required to prevent over-braking / wheel locking when unladen. Hydraulic breakaway failsafe system also required. Larger diameter (½") hydraulic brake hoses would improve system response characteristics;

- **30 mph / 50 km/h:-** Abovementioned modifications would potentially deliver acceptable braking performance at 30 mph / 50 km/h but (i) the absence of a sprung drawbar and (ii) trailer volumetric carrying capacity of 16.8 tonnes (wheat) when chassis originally designed for 12 tonnes, suggests that frequent operation at such speeds may be unwise.

*Parking Brake:* Totally inadequate performance. Means of application and (possibly) number of axle braked require revision.

**Cost / Feasibility of Upgrade**

- Trailer axles, foundation brakes and suspension are suitable for higher speed use, but trailer chassis design and construction may not be sufficiently robust to withstand increased loadings associated with higher speed operation;

- All modifications required (larger brake rams, load sensing and breakaway failsafe systems, larger brake hoses) are easily retrofitted on-farm, but trailer residual value may not warrant the investment;

**Likely Costs:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Larger (Ø 25 mm) brake rams</td>
<td>£100</td>
</tr>
<tr>
<td>ii) Larger (½”) diameter hydraulic brake hoses</td>
<td>£100</td>
</tr>
<tr>
<td>iii) Hydraulic breakaway failsafe system</td>
<td>£350 - 400</td>
</tr>
<tr>
<td>iv) Hydraulic load sensing</td>
<td>£300 - 350</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>£850 - 950</strong></td>
</tr>
</tbody>
</table>
APPENDIX 2.6: VEHICLE No.6 – 16 TONNE TANDEM-AXLE GRAIN TRAILER - 1978

A2.6.1 Specification and Condition

| Type: | Tandem-axle grain trailer |
| Nominal capacity: | 16 - 17 tonnes |
| Body volume: | ~21 m³ |
| Year of manufacture: | 1978 |
| Age at time of test: | 30 years (re-bodied in 2007) |
| Axle Suspension: | Mono-leaf springs plus trailing arms |
| Drawbar Suspension: | None |
| Axle type: | ROR 10-stud – Ø 127 mm |
| Service Brake system: | Single-line hydraulic incl. electro-hydraulic breakaway failsafe system |

| Brake size / type: | Ø 420 mm x 180 mm wide drum – S-cam (commercial) |
| Brake Ram: | Ø 22.2 mm x 76 mm stroke (Ø 7/8” x 3” stroke) |
| No. of Rams per axle: | 1 |
| Brake hose diameter: | ¼” |
| Brake Lever Arm: | Manual screw-type slack adjuster |
| Parking Brake system: | Cable-operated – Multi-pull ratchet-type on front axle only |
| Bogie wheelbase: | 1.37 m |
| Wheel track: | 1.80 m |
| Tyre size: | 425/65 R22.5 (commercial) |
| Tyre pressure: | 6.2 bar |
| Static Loaded Radius (measured): | 0.54 m |

General Condition: One of a fleet of five similar 16-17 tonne trailers used by a large (2000 ha) East Anglian farming estate for frontline transportation of grain, sugar beet, manure & other bulk materials. In extremely good condition for age, having been overhauled and re-bodied (by farm workshop staff) during the preceding year, following failure of the original body due to long-term corrosion. Braking system & undergear, etc normally overhauled annually prior to cereal harvest.

Table A2.6.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>3000</td>
<td>9,250</td>
<td>9,250</td>
<td>21,500</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>510</td>
<td>2,150</td>
<td>2,100</td>
<td>4,760</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>3,220</td>
<td>8,950</td>
<td>9,120</td>
<td>21,290</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,820</td>
<td>8,660</td>
<td>9,580</td>
<td>21,060</td>
</tr>
</tbody>
</table>
A2.6.2 Braking System Maintenance - Comments

- The vehicle had received a thorough service prior to the 2007 (cereal) harvest: a routine repeated annually. Nonetheless, this was the most elderly ‘frontline’ trailer considered by the investigation: age-related shortfalls were therefore a strong possibility;

- Brake shoe friction lining thickness was acceptable (9.5 – 15.0 mm: 5 mm minimum), reflecting the longevity of ‘commercial-spec.’ foundation brakes in agricultural applications. However, the lower brake shoes on the front axle exhibited sign of corrosion and consequent separation at the friction material / shoe interface (these being riveted linings) (see Figure A2.6.1), probably a result of moisture ingress and passage of time. The brake shoes on the front axle were therefore replaced with re-lined exchange units;

- Certain of the brake drums exhibited slight scoring, but not enough to warrant replacement;

- The trailer was unique amongst those investigated in that it utilised only one (imperial) brake ram per axle. Brake ram travel was not excessive, but was adjusted with ease by means of the external screw-type slack adjusters incorporated in brake lever arms (see Figure A2.6.1 - arrowed);

- Parking brake mechanism required no attention other than routine lubrication.
A2.6.3 Braking System Performance

Service Brake

(see Figure A2.6.2)

Trailer No.6 achieved a reasonable level of performance in ‘As-Found’ condition, but fell short of current UK statutory / BS 4639 requirements. Nonetheless, it demonstrated a strong, linear increase in braking efficiency with respect to line pressure, indicating that the system was not being compromised by the brake actuating rams reaching end travel.

‘Post-Maintenance’ performance was substantially better, but only just exceeded UK service brake performance requirements for <= 20 mph trailer operation at 100 bar line pressure. As in previous cases, this would provide little margin to accommodate the inevitable degradation in system performance between (annual ?) servicing.

Parking Brake

(see Figure A2.6.3)

Parking brake performance was largely identical ‘As-Found’ and ‘Post-Maintenance’, suggesting this is a true reflection of the system’s ultimate capability. Unfortunately, this amounted to only 29% of the performance requirement stipulated by BS 4639:1987 and current draft EU agricultural vehicle braking regulations, indicating the need either for higher parking brake application force levels and/or application of the system to both trailer axles instead of the current one.
A2.6.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:-** Acceptable, but little additional margin to accommodate likely reduction in braking performance during service;
- **25 mph / 40 km/h:-** Unsuitable in present form. Axles, foundation brakes and suspension / undergo all suitable for use at this speed and hydraulic fail-safe system already installed. Trailer requires greater braking performance: easily achieved by installation of larger diameter (e.g. Ø 30 mm) brake rams, two per axle instead of current single ram. Will then require load sensing system to prevent over-braking / wheel locking when unladen. Larger diameter (½”) hydraulic brake hoses would improve system response characteristics when larger rams are fitted;
- **30 mph / 50 km/h:-** Abovementioned modifications are likely to be adequate;

Parking Brake:- Inadequate performance at present. Means of application and (possibly) number of axle braked require revision.

Cost / Feasibility of Upgrade

- Trailer axles, foundation brakes and suspension are suitable for higher speed use;
- Trailer chassis and body easily capable of a further 15 years frontline service;
- Vehicle simply requires larger brake rams, load sensing and larger brake hoses, all which may be easily retrofitted on-farm.

Likely Costs:

1) Larger (Ø 30 mm) brake rams £125
2) Larger (½”) diameter hydraulic brake hoses £100
3) Hydraulic load sensing £300 - 350

Total = £525 - 575
APPENDIX 2.7:- VEHICLE No.7 – 14 TONNE TANDEM-AXLE DUMP TRAILER - 1993

A2.7.1 Specification and Condition

Type: Tandem-axle dump trailer
Nominal capacity: 14 tonnes
Body volume: ~16 m³
Year of manufacture: 1993
Age at time of test: 15 years
Axle Suspension: Rocking (pivot) beam
Drawbar Suspension: None
Axle type: Colaert 10-stud – 90 mm square stub

Service Brake system: Single-line hydraulic
Brake size / type: Ø 400 mm x 80 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 20 mm x 75 mm stroke
No. of Rams per axle: 2 (1 ram per stub axle end)
Brake hose diameter: ¼”
Brake Lever Arm: Splined-type retained by circlip
Operating radius: 188 mm
Parking Brake system: Cable-operated – but operating lever & cable missing

Bogie wheelbase: 1.30 m
Wheel track: 2.06 m
Tyre size: 385/65 R22.5 (commercial)
Tyre pressure: 6.0 bar

General Condition:- One of a pair of ~14 tonne dumper trailers from a large (2000 ha) East Anglian mixed farming estate. Used primarily for transporting sugar beet from harvester to field clamp. Showing numerous signs of wear and some significant repair, but nonetheless remains largely functional. No signs of recent maintenance, but had only just completed the sugar beet harvesting season.

Table A2.7.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>3,730</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>2,950</td>
<td>8,500</td>
<td>8,500</td>
<td>n/s</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>410</td>
<td>1,640</td>
<td>1,700</td>
<td>3,750</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>3,140</td>
<td>7,650</td>
<td>8,020</td>
<td>18,810</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>2,440</td>
<td>7,420</td>
<td>7,820</td>
<td>17,680</td>
</tr>
</tbody>
</table>
A2.7.2 Braking System Maintenance - Comments

- The vehicle had recently completed the 2007-08 sugar beet campaign and (prior to being pressure-washed for the purposes of the investigation) showed no signs of recent maintenance. Well-used but nonetheless robust condition;

- Wheel hub / brake drum removal showed signs of liquid mud ingress and surface contamination of brake linings, return springs and actuating components. Slight (but acceptable) scoring of brake drum wearing surfaces. Of greater concern was layer of surface rust on interiors of certain drums (see Figure A2.7.1) suggesting they had not witnessed brake shoe contact for some time !;

- Brake shoe friction lining thickness found to be acceptable (6.3 – 8.0 mm), but high wear rates are not to be expected if the brakes shoes are not making contact with the drums;

- Brake ram travel (with brakes fully-applied) was at the maximum possible level (~75 mm) for 3 of the 4 brake rams (see Figure A2.7.1). The rams had reached their end-travel and were no longer transmitting force to the trailer braking system. Repositioning the brake lever arms on the camshaft splines reduced maximum ram travel to more acceptable levels (40 – 45 mm) and restored braking system functionality. Wear was present on the brake camshafts and pivot brackets;

- The parking brake system (control lever and wire rope) were no longer present on the vehicle.
Figure A2.7.2  Trailer No.7 service brake performance test results

(arrow denotes UK statutory performance level: ~25% efficiency at 100 bar)

A2.7.3  Braking System Performance

Service Brake

(see Figure A2.7.2)

In ‘As-Found’ condition Trailer No.7 achieved a woefully-inadequate level of braking performance, demonstrating virtually no increase in braking efficiency at higher line pressures and falling well short of current UK statutory / BS 4639:1987 requirements. This was due primarily to system being compromised by the brake actuating rams reaching their end-travel and therefore failing to apply significant force to the brake shoes and drums.

‘Post-Maintenance’ performance demonstrated a dramatic improvement, but just failed to meet UK service brake performance requirements for <= 20 mph trailer operation at 100 bar line pressure. This is likely to be due in part to cumulative wear within the service brake system, but primarily to inadequate brake ram diameter / actuator force for this size of trailer. Installation of Ø 25 mm brake rams would enable the trailer to meet (current) statutory requirements whilst providing a margin to accommodate the inevitable degradation in system performance during (annual ?) service intervals.

Parking Brake

Whilst originally installed by the vehicle’s manufacturer, the passage of time had witnessed the removal of the parking brake actuating lever and quadrant plus the associated wire cable. It was therefore not possible to assess the performance of this (supposedly mandatory) system.
A2.7.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h:-** Currently fails (just!) to meet UK statutory requirements. Installation of larger (Ø 25 mm) brake rams would increase braking performance to acceptable levels and provide a safety margin to accommodate system performance degradation between servicing. Larger diameter (½”) hydraulic brake hoses would also be beneficial;

- **25 mph / 40 km/h:-** Unsuitable in present form, but if modified as above (installation of Ø 25 mm brake rams) plus addition of a hydraulic breakaway failsafe system, likely braking performance (~ 35% efficiency when laden) would be reasonable in the circumstances, although theoretically still below UK statutory requirements. Unable to increase braking performance further due to inability of trailer design (rocking beam suspension and rigid drawbar) to accept a load sensing system. Fitting replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment. Additionally, it would be necessary to increase brake servicing frequency (to 6 monthly);

- **30 mph / 50 km/h:-** Trailer (chassis and suspension) design unsuitable for use at these speeds.

Parking Brake:- Requires installation (!) and revised means of application.

Cost / Feasibility of Upgrade

- Trailer body and chassis showed signs of a long and arduous working life. Will probably require replacement or serious overhaul in next 2 – 3 years;

- Proposed modifications may be performed in farm workshop. Breakaway failsafe system could subsequently be transferred to a replacement vehicle.

Likely Costs:

i) Larger (Ø 25 mm) brake rams £115
ii) Larger (½”) diameter hydraulic brake hoses £100
iii) Hydraulic breakaway failsafe system £350 - 400
iv) Replacement lever arms (incl. manual slack adjusters) £60
v) Parking brake re-installation £80

Total = £705 - 755
APPENDIX 2.8: VEHICLE No.8 – 10 TONNE TANDEM-AXLE FLATBED TRAILER - 2007

A2.8.1 Specification and Condition

Type: Tandem-axle flatbed trailer
Nominal capacity: 10 tonnes
Body volume: n/a
7.62 m long x 2.44 m wide
Year of manufacture: 2007
Age at time of test: 9 months
Axle Suspension: Multi-leaf springs
Drawbar Suspension: None
Axle type: ADR 8-stud – 80 mm square
Service Brake system: Single-line hydraulic
Brake size / type: Ø 300 mm x 60 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 20 mm x 76 mm stroke
No. of Rams per axle: 2
Brake hose diameter: ¼”
Brake Lever Arm: Splined-type retained by circlip
Parking Brake system: Cable-operated – Multi-pull ratchet-type on front axle only
Bogie wheelbase: 1.23 m
Wheel track: 1.83 m
Tyre size: 385/65 R22.5 (commercial)
Tyre pressure: 5.5 – 6.0 bar

General Condition:
Frontline ~10 tonne flatbed trailer recently purchased new by a large (2000 ha) East Anglian mixed farming estate. Used primarily for transportation of (big) bagged fertiliser and straw (Hesston-type bales). General condition reflects age (< 1 year), but evidence of intensive use. Would potentially benefit from servicing.

Table A2.8.1: Test trailer loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>2,680</td>
</tr>
<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>2,010</td>
<td>5,335</td>
<td>5,335</td>
<td>12,680</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>390</td>
<td>1,080</td>
<td>1,180</td>
<td>2,650</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>1,650</td>
<td>4,620</td>
<td>5,250</td>
<td>11,520</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>1,650</td>
<td>4,620</td>
<td>5,250</td>
<td>11,520</td>
</tr>
</tbody>
</table>
**A2.8.2 Braking System Maintenance - Comments**

- Manufactured in August 2007, the vehicle had seen quite intense use during its short lifetime, but showed no signs of (braking system) maintenance. Generally the service and parking braking systems were in good condition, but in need of adjustment and appropriate lubrication;

- Brake shoe friction lining thickness was acceptable, but progressing towards lower limits \(3.6 \text{ to } 4.0 \text{ mm recorded: 2 mm minimum permissible}\). The brake shoe pivot pin upon each drum backplate required tightening, having worked loose. The interiors of the drums and the brake shoe / backplate areas were pristine (see Figure A2.8.1), probably reflecting the vehicle’s relatively short (~9 month) working life;

- Most significant issue concerned excess brake ram travel (see Figure A2.8.1). As with many of the other test trailers, lack of brake ram and lever arm adjustment to compensate for increasing ram travel, resulting directly from brake lining wear, had caused the rams to approach / reach their end travel. Any further lining wear would have resulted in reduction of braking effort;

- Brake ram travel (with the service brakes fully applied) was reduced from ~77 mm ‘As-Found’ to ~57 mm ‘post-maintenance’: the first adjustment since manufacture. This was achieved firstly by relocating each brake lever arm to a new annular spline on the brake camshaft, and thereafter by fine adjustment of brake ram base stops (see Figure A2.8.1). Unfortunately it is was not possible to reduce ram free travel further without causing the brakes to drag when released.
A2.8.3 Braking System Performance

Service Brake  
(see Figure A2.8.2)

Trailer No.8 demonstrated intriguing brake performance characteristics in ‘As-Found’ condition: initially braking efficiency increased linearly with line pressure but subsequently reached a plateau at higher pressure values. This indicated that system performance was on the brink of being compromised by the brake actuating rams reaching end travel, albeit only under extreme braking. However, it may be argued that it is under such circumstances that maximum system performance is most desirable.

Following adjustment, system (‘Post-Maintenance’) performance improved, braking efficiency increasing linearly with line pressure and generating greater braking effort. Unfortunately, even in this condition the system failed to reach current UK statutory / BS 4639:1987 performance requirements by a considerable margin.

Parking Brake  
(see Figure A2.8.3)

Parking brake performance was actually slightly greater in ‘As-Found’ than in ‘Post-Maintenance’ condition: a scenario for which there is not a ready explanation, particularly given the (expected) improvement in service brake performance following overhaul. Nonetheless, even the parking brake’s best performance still amounted to only 30% of the requirement stipulated by BS 4639:1987 and current draft EU agricultural vehicle braking regulations, indicating once again the need either for higher parking brake application force levels and/or application of the system to both trailer axles instead of the current one.
A2.8.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

• **20 mph / 32 km/h:-** Currently fails to meet UK statutory performance requirements. Installation of larger (Ø 25 mm) brake rams would increase braking performance to acceptable levels and provide a safety margin for system performance degradation between servicing, but the foundation brake is reaching the limits of its capability. Larger diameter (¾ or ½”) hydraulic brake hoses would also improve system response;

• **25 mph / 40 km/h:-** Axle and foundation brake size are unsuitable for fully-loaded operation at these speeds: larger brakes (e.g. Ø300 x 90 mm) are required. Given larger brakes, the existing (Ø 20 mm) brake rams would potentially be acceptable, if matched with lever arms of sufficient length. Replacement lever arms should incorporate screw-type slack adjusters to assist and encourage regular brake adjustment. Addition of a hydraulic breakaway failsafe system would also be necessary;

• **30 mph / 50 km/h:-** Abovementioned modifications may provide sufficient braking capacity if larger (Ø 25 mm) brake rams are installed, but control limitations of ‘flat-cam’ brakes makes their use questionable at this speed. A load sensing system will be required to prevent over-braking / wheel locking when unladen. The axle suspension is likely to require upgrading to accommodate resulting increased braking torques. Additionally, it would be necessary to increase brake servicing frequency (to 6 monthly);

• **Parking Brake:-** Inadequate at present: requires greater mechanical advantage and possibly application to both axles.
**Cost / Feasibility of Upgrade**

- Despite the young age of trailer, the current braking system is borderline for 20 mph operation. Use at higher speeds will necessitate upgrade of the axles and braking system;
- The age, build-quality and potential working life of the vehicle arguably justifies such expenditure.

**Likely Costs:**

i) Replacement axles featuring larger brakes (2 OFF) £1100
ii) Larger (Ø 25 mm) brake rams £100
iii) Larger (½”) diameter hydraulic brake hoses £100
iv) Replacement lever arms (incl. manual slack adjusters) £60
v) Hydraulic breakaway failsafe system £350 - 400
vi) Hydraulic load sensing £300 - 350
vii) Parking brake improvements £50

**Total = £2060 - 2160**
APPENDIX 2.9:- VEHICLE No.9 – 2000 GALLON TANDEM-AXLE SLURRY TANKER - 1996

A2.9.1 Specification and Condition

Type: Tandem-axle slurry tanker
Nominal capacity: ~2000 gallons (9100 litres)
Year of manufacture: 1996
Age at time of test: 12 years
Axle Suspension: Rocking (pivot) beam
Drawbar Suspension: None
Axle type: FAD 8–stud – 80 mm square stub

Service Brake system: Single-line hydraulic
Brake size / type: Ø 300 mm x 90 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 20 mm x 75 mm stroke
No. of Rams per axle: 2 (1 ram per stub axle end)
Brake hose diameter: ¼”
Brake Lever Arm: Splined-type retained by circlip
Operating radius:
  - 200 mm (front axle)
  - 180 mm (rear axle)

Parking Brake system: Cable-operated – Multi-pull ratchet-type on front wheels only
Bogie wheelbase: 1.14 m
Wheel track: 1.90 m
Tyre size: 16.5/70 x 18 (trailer)
Tyre pressure: Not recorded, but acceptable sidewall deflection when laden

Static Loaded Radius (measured): 0.49 m

General Condition:-
2000 gal. tanker, fitted with rear-mounted 3-leg subsoil injection unit, used by a large (2000 ha) East Anglian farming estate to handle slurry produced by cattle herd & other livestock. In regularly (weekly / fortnightly) use. Vehicle service braking system subjected to thorough overhaul (by farm workshop) 3-4 weeks prior to performance evaluation, due to complaints from farm staff regarding ineffective brakes. Vehicle usually overhauled annually.

Table A2.9.1: Test tanker loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/s</td>
<td>4,120</td>
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<tr>
<td>Max. UK Laden Mass (manufacturer’s plate)</td>
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<td>7,500</td>
<td>7,500</td>
<td>n/s</td>
</tr>
<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>Not recorded</td>
<td>Not recorded</td>
<td>Not recorded</td>
<td>Not recorded</td>
</tr>
<tr>
<td>Laden (prior to ‘As-Found’ test)</td>
<td>1,380</td>
<td>5,610</td>
<td>5,610</td>
<td>12,600</td>
</tr>
<tr>
<td>Laden (prior to ‘Post-Maintenance’ test)</td>
<td>1,380</td>
<td>5,610</td>
<td>5,610</td>
<td>12,600</td>
</tr>
</tbody>
</table>
In response to farm staff complaints regarding ineffective brakes, the tanker’s service braking system had been subjected to a thorough overhaul (by farm workshop) 3-4 weeks prior to this evaluation of system performance. The overhaul process involved brake drum removal, cleaning and free-travel adjustment (brake lever arm re-positioning, etc), i.e. all the activities that would have been undertaken by the ‘maintenance’ element of this investigation. Consequently, this vehicle was not subjected to further workshop maintenance, but rather was considered to be in ‘Post-Maintenance’ condition when tested at the outset;

- Brake ram travel (with brakes fully-applied) was found to be ~55 mm immediately prior to system performance testing and consequently within limits of acceptability;
- The parking brake ratchet was found to be partially-seized at the time of testing and so was freed and lubricated accordingly.
A2.9.3 Braking System Performance

**Service Brake**

(see Figure A2.9.2)

The slurry tanker’s service braking system produced broadly-respectable performance ‘Post-Maintenance’, but just failed to achieve the 25% UK statutory / BS 4639:1987 requirement at 100 bar line pressure. The tanker’s braking efficiency demonstrated a strong, linear increase with line pressure, indicating effective system operation, but overall system performance could have benefitted from being 10 – 15% greater at any given pressure, to provide a margin to accommodate inevitable system performance degradation during (annual ?) service intervals. Such an improvement would only result from installation of either larger diameter brake rams or larger capacity foundation brakes.

**Parking Brake**

(see Figure A2.9.3)

Parking brake performance in ‘Post-Maintenance’ condition was found to be 29% of the requirement stipulated by BS 4639:1987 and current draft EU agricultural vehicle braking regulations, indicating once again the need either for higher parking brake application force levels and/or application of the system to both axles instead of the current one, the latter not being a particularly convenient installation option for vehicles fitted with rocking beam undergear such as this.
A2.9.4 Need for (and Feasibility of) Braking System Upgrade

Suitability of braking system for operation at maximum speeds of :-

- **20 mph / 32 km/h**: Currently just fails to meet UK statutory requirements. Installation of larger (Ø 25 mm) brake rams would increase braking performance to acceptable levels and provide a safety margin to accommodate system performance degradation between servicing. Larger diameter (½”) hydraulic brake hoses would also be beneficial;

- **25 mph / 40 km/h**: Unsuitable in present form, but if modified as above (installation of Ø 25 mm brake rams) plus addition of an hydraulic breakaway failsafe system, likely braking performance (~ 35% efficiency when laden) would be reasonable in the circumstances, although theoretically still below UK statutory requirements. Unable to increase braking performance further due to inability of tanker design (rocking beam suspension and rigid drawbar) to accept a load sensing system. Fitting replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment. Additionally, it would be necessary to increase brake servicing frequency (to 6 monthly);

- **30 mph / 50 km/h**: Tanker (chassis and suspension) design unsuitable for use at these speeds.

**Parking Brake**: Currently ineffective. Means of application and mechanical effectiveness requires improvement.

![Figure A2.9.3 Slurry tanker parking brake performance test results](image-url)
Cost / Feasibility of Upgrade

- Tanker body and chassis generally in good condition and, subject to adequate maintenance, capable of a further 5 – 8 years (min.) further service;

- Minor (farm workshop) upgrading modifications would permit safe operation at 25 mph / 40 km/h, but current rigid drawbar and rocking-beam undergear largely rules out higher-speed operation without excessive modification, which is unlikely to be economic in the circumstances.

Likely Costs:

i) Larger (Ø 25 mm) brake rams £115
ii) Larger (½”) diameter hydraulic brake hoses £100
iii) Replacement lever arms (incl. manual slack adjusters) £60
iv) Hydraulic breakaway failsafe system £350 - 400
v) Parking brake improvements £50

Total = £675 - 725
APPENDIX 2.10:- VEHICLE No.10 – BIG SQUARE BALER - 2007

A2.10.1 Specification and Condition

Type: Large square baler
Nominal capacity: n/a
Year of manufacture: 2007
Age at time of test: 9 months
Axle Suspension: None – single, rigid axle
Drawbar Suspension: None
Axle type: Colaert 8-stud – 90 mm square

Service Brake system: Single-line hydraulic
Brake size / type: Ø 400 mm x 80 mm wide drum - flat cam (agricultural)
Brake Ram: Ø 30 mm x 75 mm stroke
No. of Rams per axle: 1
Brake hose diameter: ¼"
Brake Lever Arm: Splined-type retained by circlip
Operating radius: 163 mm

Parking Brake system: Cable-operated – Multi-turn screw handle-type
Bogie wheelbase: n/a
Wheel track: 2.0 m
Tyre size: 600/55 x 22.5 12PR (flotation)
Tyre pressure: 1.95 bar

General Condition:- Baler drawn from the hire fleet of a large Eastern England agricultural engineering dealership, having completed one season’s work (Summer 2007). In very good condition overall, but braking system showed no evidence of maintenance since manufacture.

Table A2.10.1: Test baler loading information

<table>
<thead>
<tr>
<th>Loading Condition (plus information source / occasion)</th>
<th>Drawbar Load (kg)</th>
<th>Front Axle Load (kg)</th>
<th>Rear Axle Load (kg)</th>
<th>Gross Vehicle Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unladen (manufacturer’s plate)</td>
<td>n/s</td>
<td>n/s</td>
<td>n/a</td>
<td>7,300</td>
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<td>Max. UK Laden Mass (manufacturer’s plate)</td>
<td>1,300</td>
<td>6,800</td>
<td>n/a</td>
<td>8000</td>
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<tr>
<td>Unladen (in ‘As-Found’ condition)</td>
<td>1,290</td>
<td>6,040</td>
<td>n/a</td>
<td>7,330</td>
</tr>
<tr>
<td>(Un)-Laden (prior to ‘As-Found’ test)</td>
<td>1,290</td>
<td>6,040</td>
<td>n/a</td>
<td>7,330</td>
</tr>
<tr>
<td>(Un)-Laden (prior to ‘Post-Maintenance’ test)</td>
<td>1,290</td>
<td>6,040</td>
<td>n/a</td>
<td>7,330</td>
</tr>
</tbody>
</table>
A2.10.2 Braking System Maintenance - Comments

- Having been manufactured in 2007 and only seen service during that year’s harvest, the baler was in very good condition. Its braking system showed no signs of having received any maintenance, but was generally in good condition, needing nothing other than cleaning, lubrication and minor adjustment;

- The interiors of the drums and the brake shoe / backplate areas were pristine, reflecting the vehicle’s relatively short (~3 month?) working life to-date. However, significant amounts of harvest debris (dust and chaff) had accumulated between the brake shoes and drum back-plates, potentially posing a fire risk;

- Brake shoe friction lining thickness was almost ‘as-new’ (7.3 – 8.8 mm recorded: 2 mm minimum permissible), but the lining surfaces were somewhat glazed, possibly due to the moderate application forces resulting from the single Ø 30 mm brake ram;

- Brake ram travel in ‘as-found’ condition (with brakes fully-applied) was ~60 mm and would have benefitted from slight reduction (~75 mm max. travel being available before ram reaching end-travel). Unfortunately, the only means of adjustment available involved repositioning each brake lever arm on a new annular spline on the brake camshafts, no fine adjustment being possible due to the fixed ram mounting. Such coarse adjustment resulted in the brakes dragging when released so, reluctantly, the lever arms were returned to their original positions. The service braking system was still completely functional in this state, but further brake lining wear would have to occur before the system could be adjusted without causing the brakes to bind;

- The parking brake ratchet was found to be in perfect working order, requiring no attention.
A2.10.3 Braking System Performance

Service Brake
(see Figure A2.10.2)

The big baler achieved a reasonable level of performance in ‘As-Found’ condition, but just fell short of current UK statutory / BS 4639:1987 requirements. Nonetheless, it demonstrated a strong, linear increase in braking efficiency with respect to line pressure, indicating that the system was not being compromised by the brake actuating rams reaching end travel;

‘Post-Maintenance’ performance was marginally better than that achieved in ‘As-Found’ condition, but this improvement was due solely to removal of glazing from the brake shoes and debris from within the brake drums. Unfortunately, the system still failed to meet UK service brake performance requirements for \( \leq 20 \) mph operation, due almost certainly to inadequate brake (camshaft) application forces. The latter could be easily addressed, either by fitting a slightly larger diameter brake ram (\( \Theta 35 \text{ mm} \) instead of \( \Theta 30 \text{ mm} \)) and/or by attaching the ram to an alternative hole on each brake lever arm, thereby increasing its effective operating radius and the resulting maximum camshaft torque and brake application force.

Parking Brake
(see Figure A2.10.3)

The big baler was unique amongst the vehicles tested in that it met (and exceeded) the parking brake performance requirements stipulated by BS 4639:1987 and the current draft EU tractor-trailer braking regulations. The reasons for this were twofold. The baler’s mass was much lower (~45%) than the majority of the test vehicles, and whilst it used comparably-sized foundation brakes, only a single axle was braked. Consequently, the performance of its service brake system was similar to many of the other test vehicles. However, the baler’s parking brake acted upon all the vehicle’s available axles (one), whereas those of the other test vehicles only acted on one axle of a tandem bogie. Thus, if considering the parking brake force generated as a proportion of vehicle mass, the baler could immediately generate twice as much as the other vehicles.
Additionally, the baler’s screw-type parking brake control (see Figure A2.10.1) was capable of generating much greater brake application forces than the more common multi-pull ratchet or lever and quadrant types fitted to the other test vehicles. Consequently, a combination of greater (parking) foundation brake capability and potentially higher application forces paid indisputable dividends.

**A2.10.4 Need for (and Feasibility of) Braking System Upgrade**

**Suitability of braking system for operation at maximum speeds of :-**

- **20 mph / 32 km/h:-** Currently just fails to meet UK statutory (C&U) requirements. Installation of larger (Ø 35 mm) brake ram would increase braking performance to acceptable levels and provide a safety margin to accommodate system performance degradation between servicing. Larger diameter (¼”) hydraulic brake hose would improve system response;

- **25 mph / 40 km/h:-** Unsuitable in present form, but if modified as above (*installation of Ø 35 mm brake rams*) plus attachment of brake ram at a greater lever arm radius (e.g. ~190 mm), braking performance could be increased to an acceptable level (~ 33% efficiency), albeit theoretically still below UK statutory requirements. It would be necessary to install a hydraulic breakaway failsafe system. Installation of replacement brake lever arms (incorporating screw-type slack adjusters) would assist and encourage regular brake adjustment;
• **30 mph / 50 km/h:** Baler not really suitable for use at these speeds, even if modified as stated above, because:
  • Control limitations of ‘flat-cam’ brakes at higher speeds;
  • The machine’s axle is rigidly-mounted.

A load-sensing braking system is not required in this instance as the baler’s mass varies little in service. Nonetheless, arguably better to select the suspended tandem-axle bogie option offered by the baler manufacturer if frequent use at these speeds is envisaged.

**Parking Brake:** System performance is totally acceptable.

**Cost / Feasibility of Upgrade**

• Simple, farm workshop-type modifications to permit safe 20 or 25 mph operation;
• Better to choose the (optional) suspended tandem-axle bogie undergear if the baler is likely to be used behind a 30 mph / 50 km/h tractor.

**Likely Costs:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Larger (Ø 35 mm) brake ram</td>
<td>£25</td>
</tr>
<tr>
<td>ii) Larger (⅜”) diameter hydraulic brake hose</td>
<td>£50</td>
</tr>
<tr>
<td>iii) Replacement lever arms (incl. manual slack adjusters)</td>
<td>£50</td>
</tr>
<tr>
<td>iv) Hydraulic breakaway failsafe system</td>
<td>£350-400</td>
</tr>
</tbody>
</table>

**Total = £475 - 525**
Appendix 3 Agricultural Trailer Braking Equipment Suppliers

The following listing is by no means exhaustive, but features suppliers agricultural trailer braking equipment and running gear (axles and suspensions) with whom this investigation has had contact and, as such, are potential sources of technical information and components for upgrading and servicing trailer braking systems.

### Commercial & Agricultural Axle (and Brake) Suppliers

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Address</th>
<th>Website</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPW Ltd</td>
<td>Legion Way, Leicester</td>
<td><a href="http://www.bpw.co.uk">www.bpw.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>LE19 1UZ</td>
<td></td>
</tr>
<tr>
<td>Granning Axles</td>
<td>Naas Industrial Estate, Naas Co. Kildare</td>
<td><a href="http://www.granningaxles.ie">www.granningaxles.ie</a></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hunton Legg Ltd</td>
<td>Bridge Works, Bruisyard, Saxmundham, Suffolk</td>
<td><a href="http://www.huntonlegg.co.uk">www.huntonlegg.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>IP17 2DT</td>
<td></td>
</tr>
<tr>
<td>Tyremart (Agricultural) Ltd</td>
<td>Main Road, Long Bennington, Newark, Notts</td>
<td><a href="http://www.tyremartagri.co.uk">www.tyremartagri.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>NG23 5DJ</td>
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### Agricultural Trailer Braking Equipment Suppliers

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Address</th>
<th>Website</th>
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</thead>
<tbody>
<tr>
<td>Erentek Ltd</td>
<td>Malt Kiln Lane, Waddington, Lincoln</td>
<td><a href="http://www.erenetek.co.uk">www.erenetek.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>LN5 9RT</td>
<td></td>
</tr>
<tr>
<td>GES Hydraulics Ltd</td>
<td>Unit 3, Nene Terrace, Thorney Road, Crowland</td>
<td><a href="http://www.geshydraulics.co.uk">www.geshydraulics.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>Peterborough, PE6 0LD</td>
<td></td>
</tr>
<tr>
<td>J.H. Milnes Ltd</td>
<td>New Chapel Farm, Chapel Lane, Penistone</td>
<td><a href="http://www.eurosafebraking.com">www.eurosafebraking.com</a></td>
</tr>
<tr>
<td></td>
<td>Sheffield, S36 6AQ</td>
<td></td>
</tr>
<tr>
<td>Tractair Ltd</td>
<td>Hytec Way, Saltgrounds Road, Brough, East</td>
<td><a href="http://www.tractair.co.uk">www.tractair.co.uk</a></td>
</tr>
<tr>
<td></td>
<td>Yorkshire, HU15 1UD</td>
<td></td>
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</table>
In-service assessment of agricultural trailer and trailed appliance braking system condition and performance

The Agricultural Trailer Braking Study

The service and parking brake performance of a small but representative range of frontline agricultural trailers and trailed appliances from UK farms was quantified, to highlight possible inadequacies in trailer braking system specification and maintenance levels, particularly when used with faster (above 20 mph) tractors.

Braking performance was determined both in ‘As-Found’ off-farm condition and following maintenance. ‘As-Found’, 90% of test vehicles failed to meet UK statutory service brake performance requirements for vehicles travelling up to 20 mph, and 40% of parking brakes were inoperative. Following maintenance, 40% of vehicles achieved/exceeded the statutory service brake requirement and a further 20% approached the required performance level. Nonetheless, 40% of these modern and supposedly serviceable vehicles still failed to demonstrate adequate performance. Only one parking brake met the requirements stipulated by BS 4639:1987 and the proposed (draft) EU braking regulations for towed agricultural vehicles, either ‘As-Found’ or ‘Post-Maintenance’.

The requirements of existing and future UK and European agricultural vehicle braking legislation are reviewed. The vehicles tested are presented as case studies, considering the need for, and practical and economic feasibility of, upgrading their braking systems to permit safe (and legal) operation at 20, 25 and 30 mph maximum speeds. The construction and operation of agricultural trailer braking systems are reviewed and recommendations made regarding selection for typical UK agricultural applications.

Future EU tractor-trailer braking legislation is likely to require significantly greater performance. This can be achieved without undue difficulty or excessive cost, but there is a vital need to raise user awareness and understanding of trailer and trailed appliance braking system specification and selection, to minimise future performance shortfalls.

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