A GUIDE TO THE APPLICATION AND USE OF SUSPENSIONS ON MULTI-COMBINATION VEHICLES

August 2005

Image courtesy of SFM Engineering Pty Ltd

ARTSA
AUSTRALIAN ROAD TRANSPORT SUPPLIERS ASSOCIATION

Foreword

Mr Ian Bushby
Chairman ARTSA

The Australian Road Transport Suppliers Association Inc. (ARTSA) is an industry Association with over 35 members from the component and Original Equipment Manufacturers (OEM) sector. It is focused on providing technical expertise and representation to improve safety, productivity and efficiency in many aspects of the road transport industry.

This publication has arisen from a significant research project concerned with the on-road behaviour of multi-combination vehicles fitted with air suspension systems. The project, 'Stability and on-road performance of multi-combination vehicles with air suspension systems', was instigated by the Remote Areas Group (RAG) to address concerns raised by operators regarding inadequate dynamic stability of certain multi-combination vehicles. Stage One and Two were managed by the WA Department for Planning and Infrastructure (DPI) on behalf of RAG.

The project reports are available at:
http://www.ntc.gov.au/ViewPage.aspx?page=A02311403400370020

The third and final stage of the project was the preparation of this Guide, which has been published by ARTSA with the aid of a grant from the National Transport Commission (NTC), to advance the knowledge and practices of the road transport industry in Australia.

ARTSA assembled a steering committee consisting primarily of ARTSA members and industry stakeholders to manage the preparation of this Guide. Considerable technical input was received from the steering committee, which I gratefully acknowledge. The team included:

Mario Colosimo (BPW Transpec)	Chairman of the Committee
Rob Di Cristoforo (ARRB Group Ltd)	Author/Editor
Rob Perkins (ARTSA)	Project Manager
Scott McFarlane (Hendrickson Asia-Pacific)	Committee Member
John Zhang (Marshall Lethlean Industries)	Committee Member
Mark Boon (Holland Hitch)	Committee Member
Ian Wright (Ian Wright & Associates)	Committee Member
Doug McDonald (SFM Engineering)	Committee Member
Rex Middleton (DPI WA)	Committee Member

The assistance of John Dombrose (DPI WA) and Barry Hendry (NTC) is also acknowledged.

This is a living document that is intended to be updated from time to time as new knowledge emerges on the application and use of suspensions on multi-combination vehicles.

Free electronic copies are available on ARTSA's web site (www.artsa.com.au) or by contacting the Executive Officer by email exec@artsa.com.au or telephone 03 9818 7899.

Ian Bushby
Chairman

Contents

Note: This document is only able to reflect the known aspects of suspension development at the time of publication. Additional information will become available from time to time and such documents may be found via the NTC website (www.ntc.gov.au) and other industry sources.

Scope of this Guide

This Guide is intended to assist people involved in the design, construction and operation of multi-combination vehicles to:

- better understand the basics of multi-combination vehicle dynamic stability
- better understand best-practice multi-combination vehicle design principles
- better understand the set-up of suspensions for multi-combination vehicles
- select suspension systems appropriate to the application
- improve the dynamic stability of multi-combination vehicles.

This Guide is not intended to cover every eventuality related to suspension performance in multi-combination use and additional advice may need to be sought for specific applications.

Introduction

There is no doubt that multi-combination vehicles are extremely efficient for freight transport in remote areas of Australia – one triple road train can haul approximately the same payload as three separate single-articulated vehicles. With the corresponding reduction in vehicle-kilometres-travelled, there is a significant safety benefit that results from reduced exposure, and a significant environmental benefit that results from reduced noise and emissions.

However, as the number of trailers and articulation points increases, the on-road behaviour of heavy combinations tends to degrade. The amount of degradation can be controlled by adopting good vehicle design principles and by operating and maintaining the combination appropriately.

Of primary importance in the design of a multi-combination vehicle is the geometric layout. The positioning of axles and couplings, the height of the load and the lengths of trailers and dolly drawbars, for example, can be designed for improved performance. Many vehicles on the road today probably are not designed as well as they could be in this regard.

Tyre selection and good tyre maintenance play an important role in the tracking ability of a vehicle. Selecting quality tyres will reduce the swaying of a vehicle, while maintaining correct operating pressures for the application will help to increase tyre life and also improve tracking.

Finally, suspension selection and set-up is a factor in the overall behaviour of a vehicle. Characteristics such as vertical stiffness, roll stiffness, roll centre height and roll steer coefficient can each affect a vehicle's behaviour in different ways. Therefore it is imperative that designers and constructors of multi-combination vehicles take reasonable steps to select the most appropriate suspension for the task, and that operators set them up and maintain them regularly and appropriately. Suspension manufacturers and suppliers are urged to provide relevant engineering details in a comprehensible manner, so that their customers can make the most informed decision.

Designing a multi-combination vehicle for best dynamic performance involves juggling many different competing goal sets. Improving performance in one area can sometimes degrade performance in another. Finding the right balance between all goal sets is a matter of experience and technical know-how.

Image courtesy of ARRB Group Ltd

Image courtesy of ARRB Group Ltd

Important considerations

Please read the following important notes.

- *Always select a suspension that is suited to the task. Price and tare mass are not the most important factors in the suspension selection process.*
- *Always install a suspension according to the manufacturer's installation procedure.*
- *Always operate a suspension according to the manufacturer's specifications.*
- *Normally there is only one correct ride height for an air suspension. Always operate a suspension at its design ride height.*
- *Always follow the suspension manufacturer's recommended procedures when adjusting the ride height of an air suspension.*
- *Always adjust the ride height of an air suspension before carrying out an alignment.*
- *With mechanical suspensions on trailers ensure that the equalisers (rockers) are parallel to the ground.*
- *Always ensure that air-suspended converter dollies with fifth wheels and hinged drawbars are properly blocked to prevent 'nose-diving'.*
- *Always operate vehicle combinations with correct skid plate heights and angles.*
- *Contact the suspension supplier and the vehicle manufacturer if a multi-combination vehicle is experiencing dynamic performance problems.*

PART I: Suspension selection, set-up and maintenance

What vehicle manufacturers and suspension suppliers need from their customers

The best way for a transport operator to make sure they have the most appropriate suspension fitted to a vehicle is to involve the suspension supplier in the initial design project. The suspension supplier, in conjunction with the vehicle manufacturer, can make more informed decisions on the recommended specification of the suspension if they have some knowledge of the operating environment and vehicle application.

Suspension suppliers, particularly for the towing vehicle, typically have a specific application approval process for supplying suspensions for road train applications. Suppliers' suspension selection processes are based on many years of practical experience with products suitable for use in specific operating conditions.

Consideration should be given to the following areas:

- vehicle configuration (e.g. triple road train, AAB-quad, B-triple)
- body type for each vehicle unit (e.g. livestock, tanker, converter dolly)
- air versus mechanical suspension
- number of axles in each axle group (e.g. single, tandem, triaxle, quad)
- area of operation (e.g. on-highway, off-highway, both)
- typical operating speed
- typical operating axle loads

The following page features a sample data form that enables operators to easily provide the information typically needed by suspension suppliers.

Suspension supplier information form

<table>
<tr><td colspan="11">Multi-combination vehicle description:</td></tr>
<tr><td colspan="2" rowspan="2"></td><td colspan="2">Vehicle 1</td><td rowspan="2">Vehicle 2</td><td rowspan="2">Vehicle 3</td><td rowspan="2">Vehicle 4</td><td rowspan="2">Vehicle 5</td><td rowspan="2">Vehicle 6</td><td rowspan="2">Vehicle 7</td><td rowspan="2">Vehicle 8</td></tr>
<tr><td>Steer</td><td>Drive</td></tr>
<tr><td colspan="2">Vehicle types (circle):

Note: Dollies and trailers must be specified as separate vehicles under the vehicle columns opposite.</td><td colspan="2">Prime mover
Rigid truck</td><td>Livestock
Tanker
Tipper
Gen Freight
Dolly
Other
_________</td><td>Livestock
Tanker
Tipper
Gen Freight
Dolly
Other
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Gen Freight
Dolly
Other
_________</td></tr>
<tr><td colspan="2">Axle groupings (circle):</td><td>1 / 2</td><td>1 / 2 / 3</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td><td>1 / 2 / 3 / 4</td></tr>
<tr><td>Laden axle loads: GCM:</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td><td>t</td></tr>
<tr><td colspan="2">Overall height</td><td colspan="2">m</td><td>m</td><td>m</td><td>m</td><td>m</td><td>m</td><td>m</td><td>m</td></tr>
<tr><td colspan="2">Operating speed:</td><td colspan="9"></td></tr>
<tr><td colspan="2">Duty:</td><td colspan="9">On highway ____% / Off highway____%

Routes:____</td></tr>
<tr><td colspan="2">Desired suspension specification (circle):
O.S. = Overslung, U.S. = Underslung</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
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O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td><td>Air / Mech
O.S. / U.S.</td></tr>
</table>

Suspension maintenance

Air suspensions are not ‘Set and Forget’ systems. They require regular maintenance to ensure that they continue to operate at their best performance. Of particular importance to combination vehicle dynamic stability is ride height, alignment and the condition of pivot bushes.

Mechanical suspensions must also be regularly maintained to ensure adequate vehicle dynamic performance. Of particular importance is spring pack condition (e.g. broken leaves), alignment and wear of pivot bushes and spring wear plates.

ARTSA’s web site (www.artsa.com.au) provides free copies of an industry guide titled ‘Air Suspension Code: Guidelines for Maintaining and Servicing Air Suspensions for Heavy Vehicles’. Please refer to that Guide for more in-depth information on air suspension maintenance.

Further information on air and mechanical suspensions can be obtained from the suspension supplier.

Air suspension ride height

Incorrect air suspension ride heights may adversely affect the dynamic stability of multi-combination vehicles and therefore ride height needs to be correctly maintained.

The vehicle’s air supply system is important for the satisfactory operation of the air suspension. A range of valves ensures that the system operates according to its design performance.

Height control valve (HCV)

There is a wide range of height control valve types available. Some are designed for hauling units, whilst others are designed for trailing units. Many hauling units are fitted with dual height control valves, including some that are electronically operated by a series of solenoid valves and sensors. Some single axle suspensions use fast response valves.

Proper ride height is especially important for driven axles, as driveline angles are directly affected by incorrect ride height, including small variations. For vehicles with dual height control valves, each OEM procedure should be followed. It is suggested that the settings made are checked with the vehicle loaded, using a duplex air pressure gauge, to ensure that the pressure output (to the airbags) of both valves is equalized.

Many newer ride height valves operate with a very simple flick of a switch. This has given rise to a grave misconception that ride height is not important and is an adjustment for driver convenience and comfort. Some suppliers fit ‘drive-away-protection’ features saving unnecessary damage as the system automatically reverts to the pre-set ride height on the first brake application, or on reaching the selected road speed. Height control valves should not be used for any reason other than to control ride height.

Normally there is only one correct ride height for each vehicle. (Refer to your manufacturer’s suspension drawing). Incorrect ride heights can lead to component failures, including poor ride, excessive vibration, shock absorber and shock absorber bush failures, as well as poor dynamic performance.

Trailing units are more likely to be fitted with mechanical height control valves. It is recommended that they are fitted along the trailer centre-line, on the axle in the centre of the axle group, and away from areas where they may sustain damage or be subject to unauthorised tampering.

Ensure that all settings and adjustments are carried out in accordance with the suspension manufacturer's procedures.

Untrained personnel should not be permitted to adjust or alter ride heights, especially on vehicles equipped with twin ride height control valves.

Measuring ride height

1. The vehicle should be unladen and parked on a level surface. Trailers should be attached to the prime mover. The air brake system pressure must be in excess of 450 kPa (600 kPa recommended) throughout the procedure. This is to ensure the pressure protection valve (PPV) opens. Ensure all tyres have the correct inflation pressure. Chock the wheels of a different axle group to the one having its ride height measured. Release the brakes.

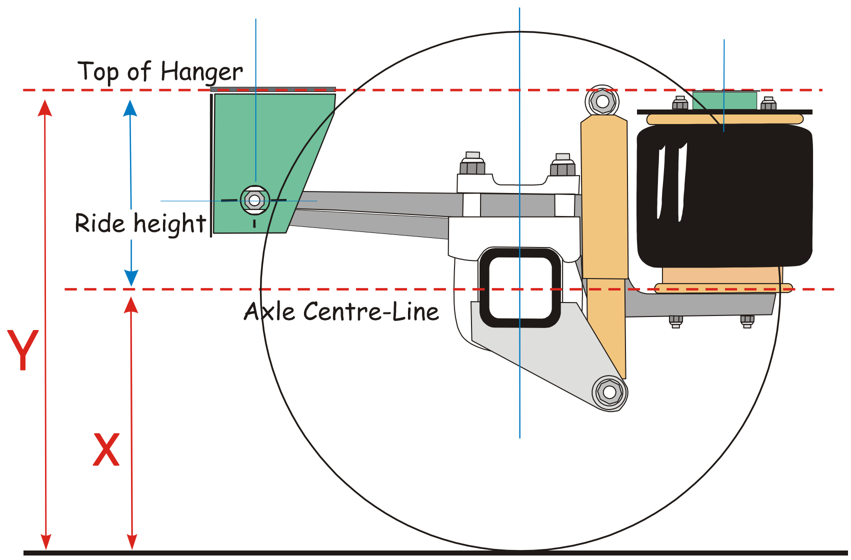
2. Measure the distance X (see illustration) from the ground to the centre of the axle which is fitted with the height control valve.

3. Measure the distance Y from the ground to the bottom of the frame at a point near the axle used in step 2.

4. The ride height is the difference between the two measurements, or Y – X = ride height. It is recommended that the ride height be permanently marked on the vehicle, e.g. on the chassis adjacent to the height control valve, or near the driver's door. It is also worth recording these measurements on the vehicle's history card.

If a trailer manufacturer's recommended ride height is unknown, the average of the highest and lowest possible settings can serve as an approximation. The highest and lowest possible settings can be determined by completely inflating the airbags and completely deflating them as described in the next section (*Adjusting ride height*).

For hauling vehicles, **it is extremely important** to follow the OEM recommended procedures so as to ensure correct driveline angles are retained.



Terminology used in ride height measurement

Adjusting ride height

Park the vehicle on a level surface.
The air brake system pressure must be in excess of 450 kPa (600 kPa recommended) throughout the procedure. Ensure the tyres are correctly inflated, wheels chocked, then release brakes. No wheels should be chocked in the axle group that is having its ride height adjusted. Chock the wheels of another axle group in the combination. Measure trailers with their skid plate set at the correct height.

Disconnect the linkage from the height control valve(s).
Adjust ride height up by rotating the HCV control arm to the ‘up’ (inflate) position. Adjust ride height down by rotating the HCV control arm to the ‘down’ (exhaust) position.

Check ride height as described in the previous section (*Measuring ride height*).
Always use the axle fitted with the HCV to take measurements. Use the manufacturer’s template or measuring tool, if available.

Adjust the length of the vertical linkage if required, and refit.
Ensure driveline angles are maintained on hauling vehicles as per the vehicle manufacturer’s recommended settings.

Do not grease the ride height valve. Do not change the manufacturer’s recommended ride height.

Alignment

For most operators, suspension alignment is carried out by the vehicle manufacturer, or sub-contractors who specialise in alignment. However it is important to have an understanding of how alignment measurements can affect a suspension's performance and what checks and remedies are available. Observe the manufacturer’s recommended settings, especially the axle’s toe-in, toe-out and camber requirements.

Alignment has implications for tyre wear as well as vehicle tracking. It is important to check and adjust the vehicle’s ride height ***before*** having the alignment checked and adjusted. Always check and replace worn pins and bushes prior to a wheel alignment.

A common practice is to carry out alignment on the trailers in a fleet without considering the towing vehicle. When performing alignments on trailers it is important to ensure that the skid plate is supported at the correct operating height - i.e. the laden height of the towing unit’s fifth wheel.

Alignment can be adjusted at either the suspension’s pivot connection or at the axle’s connection point, depending on the make and model of the suspension. Consultation with the suspension manufacturer will determine the best method of alignment.

Inspection

Indicators of possible alignment issues include excessive or uneven tyre wear, uneven braking and vehicle off-tracking.

Pivot connection points

Not all pivot connection points are adjustable. However, some trailer and drive axle suspensions employ various adjustment methods on one or both sides.

The pivot point normally has a very high torque requirement on the fixing nut and bolt. This must be torqued with the suspension at the correct ride height and maintained to ensure the pivot bush works as designed about its natural or relaxed state in the ride height position.

Axle connection points

A thru-bolt connection at the axle connection point (drive axle type) is a fixed or non-adjustable connection. At this location all that is required is periodic inspection and regular torque adjustment.

A bar pin connection is adjusted easily via the addition or subtraction of shims to move the axle forward or rearward as necessary. This is a typical drive axle connection point and is not used in a trailer application.

U-bolts

Standard and flattened U-bolts could be employed to clamp the top plate, the leaf spring or fabricated trailing arm, the axle and the bottom plate together. The U-bolts must be correctly torqued in a diagonal sequence to the OEM's recommended tension settings.

Because of the number of surfaces between these components there is a tendency for some 'settling' that, in turn, requires any resulting slack to be re-torqued. This should be done after the first 1000 or 1500 km interval following assembly of a new or repaired axle assembly.

Operators have found that suspension component failure is greatly reduced by retorquing U-bolts during the first day of service following the initial tightening.

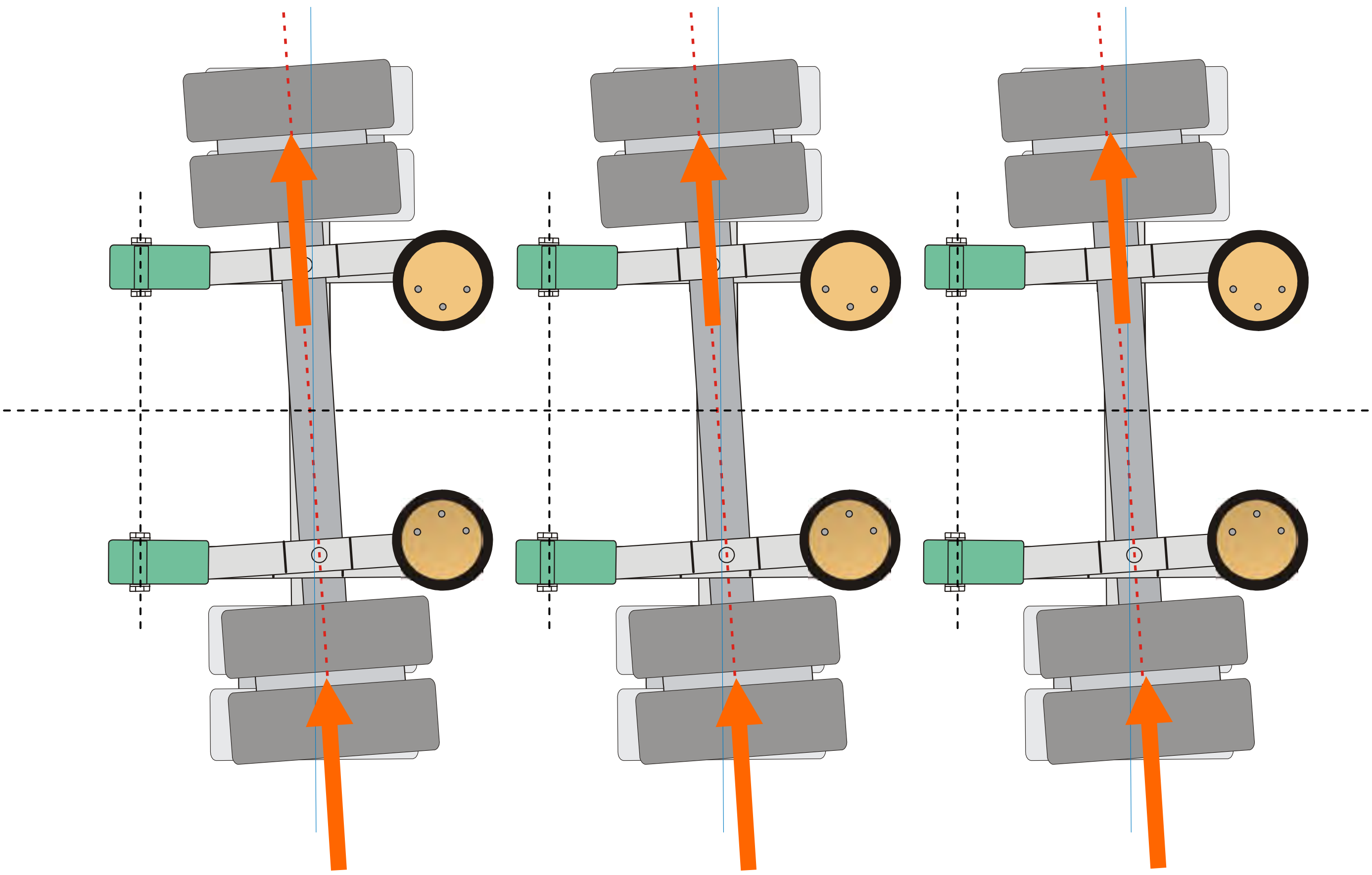
Reinforcement of hanger brackets

Compliance steer

When a vehicle travels along the road at speed, vertical, fore-aft and lateral loads are exerted on the tyres. Vertical load is almost invariably the largest component of load on a tyre, while fore-aft load is very small in constant speed travel. Significant lateral loads can be exerted during dynamic manoeuvres and travel along rough or undulating roads.

Lateral loads on the tyres can result in large forces at the pivot bushes of a trailing arm air suspension. More noticeably in trailing arm air suspensions with large compliant pivot bushes, compression of the bushes results in axle steer due to lateral load, or ‘compliance steer’ - particularly if a transverse torque rod is not fitted. Compliance steer typically causes vehicles to sway more when travelling at speed.

Regardless of the design of the bushes, if the hanger brackets are not braced properly, these forces can also distort the hanger brackets, leading to increased compliance steer.



Axle steer due to lateral load

Examples of hanger bracket reinforcement

Suspension suppliers typically provide customers with installation procedures for their products. The following drawings are examples of manufacturer-specified methods of reinforcing hanger brackets. You should consult the appropriate suspension supplier before attempting this task.

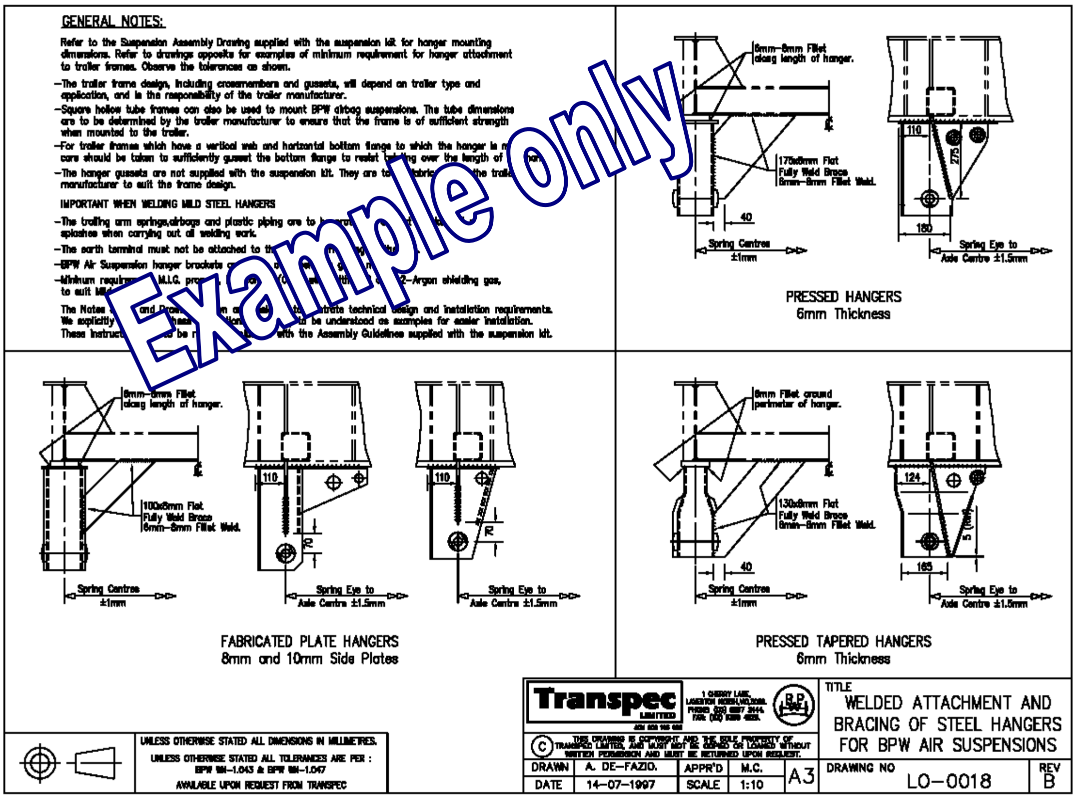


Image courtesy of BPW Transpec

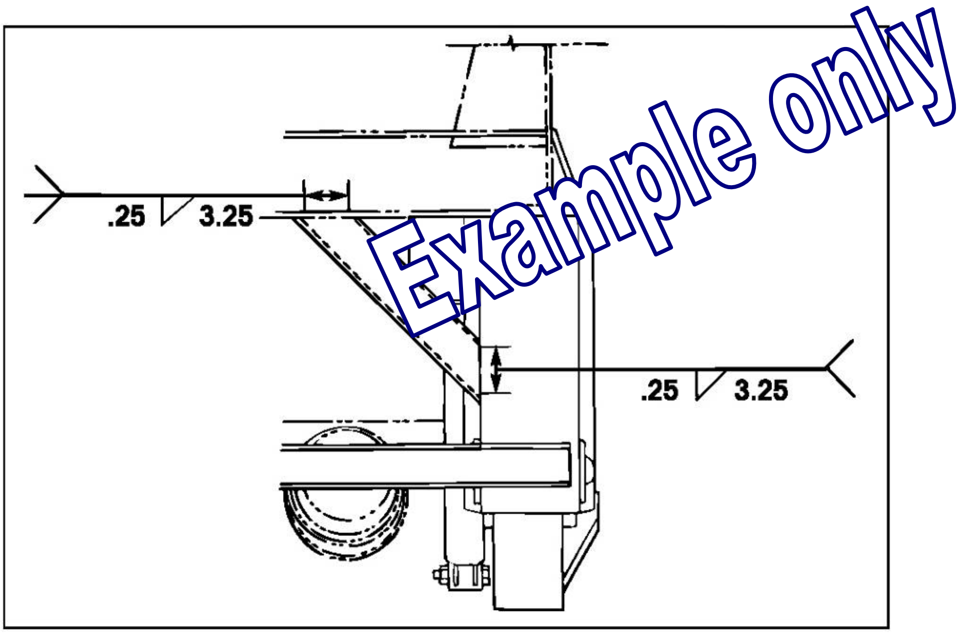


Image courtesy of Hendrickson Asia Pacific

Specifications for hanger bracket reinforcement (examples only)

PART II: Design for better vehicle dynamics

This section details a few of the many methods that engineers use to objectively measure multi-combination vehicle behaviour, and some rules of thumb for vehicle designers to apply in order to maximise performance in these measures.

Although road testing of multi-combinations is essential, the on-road behaviour of a multi-combination vehicle is not always easy to gauge by watching it from a following car or assessing it from the feel in the cab. Sometimes it is necessary to conduct instrumented testing in order to identify the cause of dynamic performance deficiencies.

Objective assessment of multi-combination vehicle behaviour

The following three objective assessment methods are among many that engineers typically use to assess the performance of a multi-combination vehicle, either by computer simulation or instrumented field testing:

- Rearward Amplification
- Yaw Damping Coefficient
- Tracking Ability on a Straight Path.

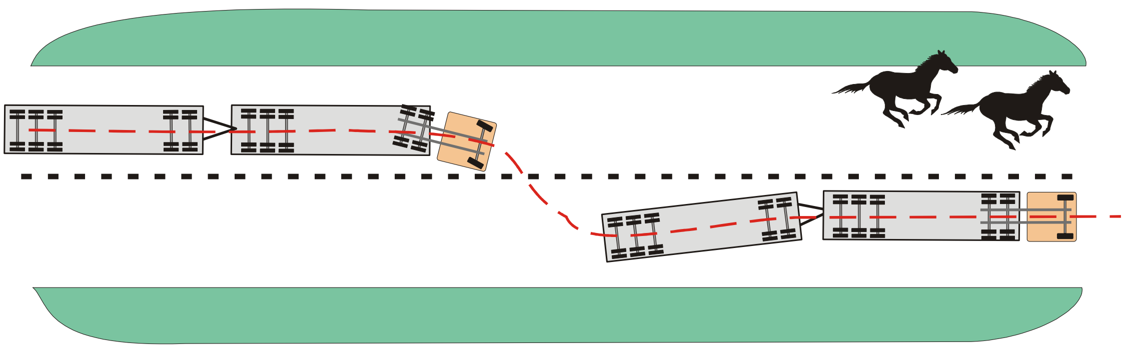
These particular methods have been addressed in this Guide because they define the main characteristics of a vehicle in terms of its directional stability.

A complete set of nationally agreed assessment methods, known collectively as *Performance Based Standards (PBS)*, has been developed by the National Transport Commission (NTC). These standards are described in simple terms in the ARTSA publication *PBS Explained*. More information on PBS can be obtained from various reports available on the NTC web site (www.ntc.gov.au).

The standards set levels of required performance which are aimed to 'raise the bar' for vehicle performance in comparison with the majority of currently operating vehicles. A vehicle which is designed to achieve the required performance should have better-than-average performance on the road.

Rearward Amplification

Rearward Amplification is the degree to which the trailing units of a combination vehicle amplify or exaggerate sideways motions of the hauling unit. An example of Rearward Amplification is the 'whip crack' effect that occurs when a driver swerves to avoid an obstacle, such as a stray beast, at high speed; the rear trailer will feel a much greater side force than the driver. Experienced drivers take this into account when undertaking severe manoeuvres.



The level of Rearward Amplification of a multi-combination vehicle can be calculated by comparing the forces acting on the front and rear of the vehicle in a severe swerving manoeuvre, to see how much greater the force is at the rear in comparison with the force at the front.

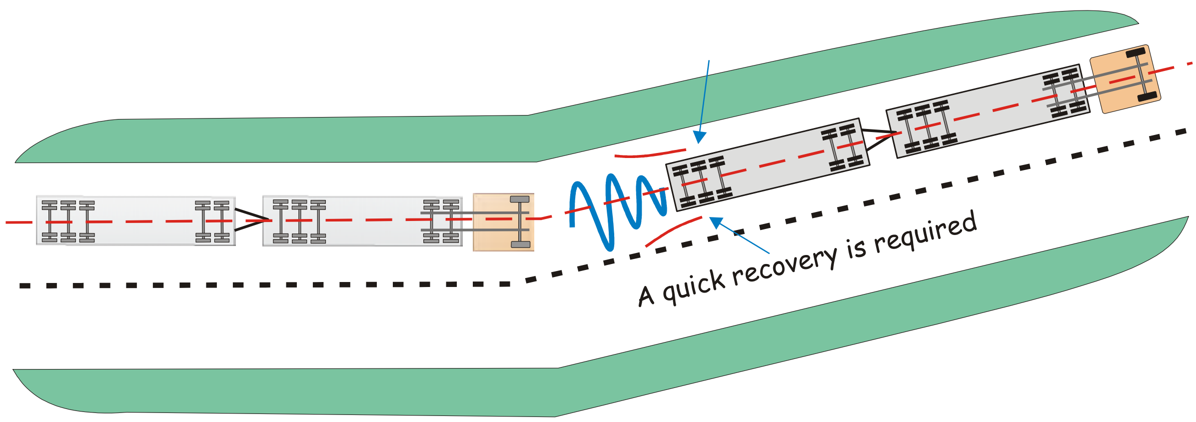
Image courtesy of ARRB Group Ltd

Rearward Amplification varies with steering frequency, so the 'whip crack' effect can be more pronounced when a certain rate of steering reversal is applied. In some cases, this rate of steering reversal may be close to the rate naturally adopted by the driver during normal travel. Attempting to correct the natural motions of the vehicle by constantly looking in the mirrors can sometimes lock the driver into the vehicle's natural frequency, causing the Rearward Amplification effect be exacerbated.

Yaw Damping Coefficient

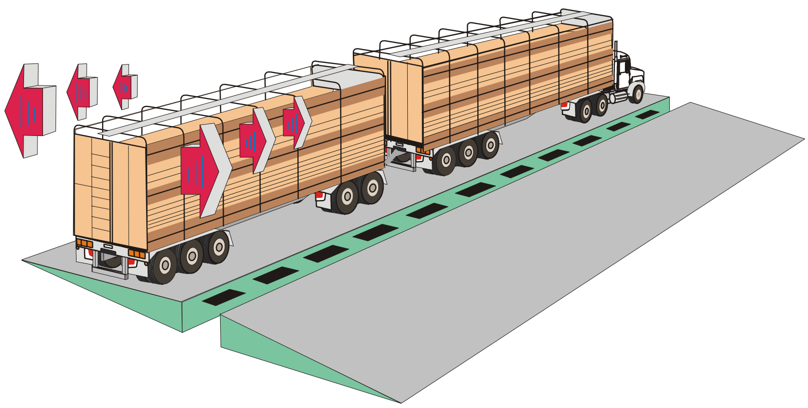
Yaw Damping Coefficient describes a vehicle's ability to settle down after a disturbance such as a dip in the road or a severe swerving manoeuvre. A vehicle with a low Yaw Damping Coefficient will tend to sway from side to side for a long period of time after an initial disturbance, making the vehicle seem unstable to the driver.

The Yaw Damping Coefficient can be determined by measuring how quickly swaying motions die away after an initial disturbance.



Tracking Ability on a Straight Path

Tracking Ability on a Straight Path is the ability of a vehicle to remain within its lane when travelling at high speed in a straight line. By running the vehicle along a section of road having a very specific level of roughness and cross-fall, engineers can measure the amount of 'swaying' in the vehicle and compare this with acceptable limits.



Rules of thumb for maximising performance

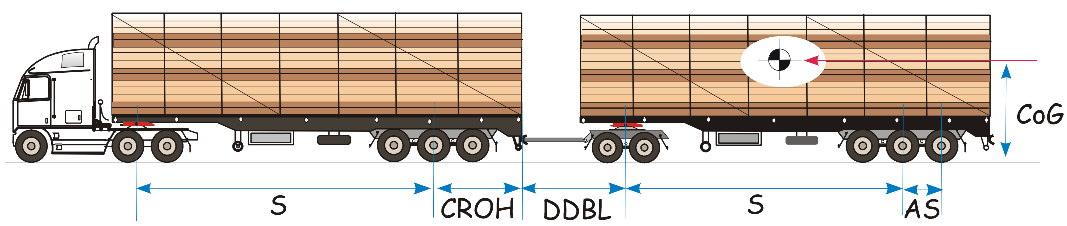
Having developed the various objective assessment techniques for multi-combination vehicle behaviour, research has been able to focus on what works and what doesn't in terms of improving multi-combination vehicle behaviour.

A lot can be achieved at the design stage by following a few simple rules of thumb. Minimising and maximising certain dimensions and consideration of the suspension design all have significant effects on the performance of the final product.

Geometry

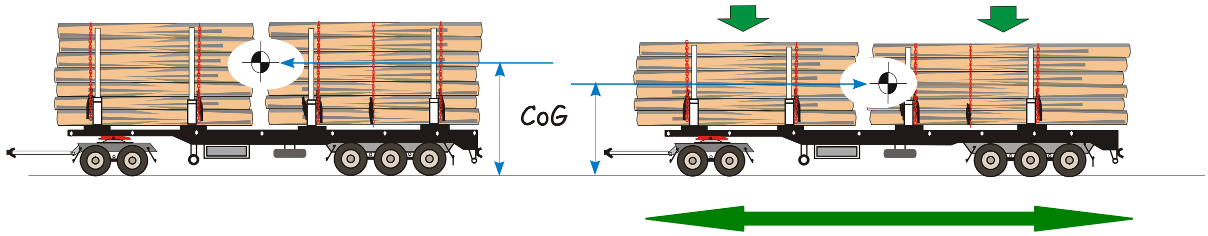
All geometric features of a multi-combination vehicle affect its behaviour in some way. Some of the more important geometric features are:

- centre-of-gravity height (CoG)
- trailer 'S' dimension (S)
- coupling rear overhang (CROH)
- axle spacing (AS)
- dolly drawbar length (DDBL).

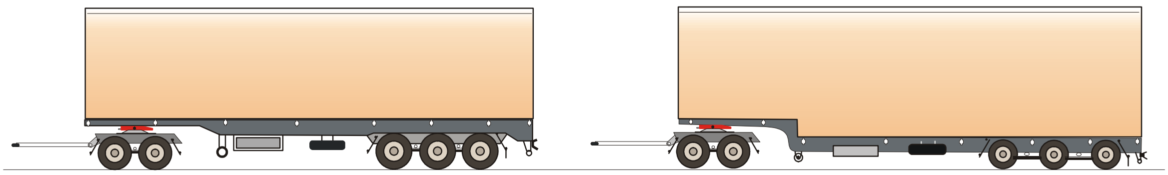


In general, it is good practice to maximise some of these dimensions and to minimise others, within the geometric limits allowed in the State or Territory of operation. The following passage gives some examples.

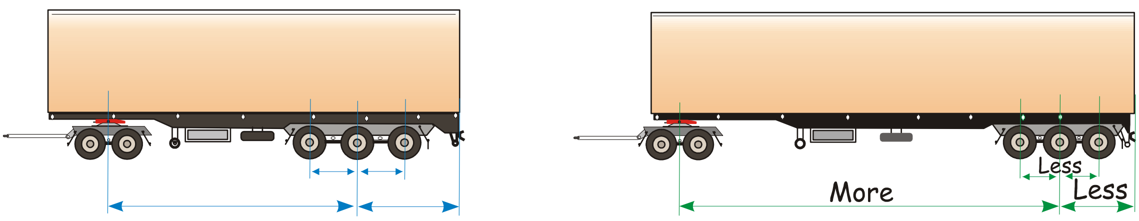
Centre-of-gravity height is the most critical geometric property affecting vehicle stability – it should be kept as low as possible. The centre-of-gravity of a trailer can sometimes be lowered by increasing trailer length and loading to a lower payload height.



A drop-deck (or step-deck) design is also very helpful for certain types of payload.



Trailer wheelbase and **coupling rear overhang** go hand-in-hand as two dimensions that can work together to 'make or break' the dynamic stability of a vehicle. The best performance is achieved when the trailer wheelbase is maximised and the coupling rear overhang is minimised. Coupling rear overhang is often driven by the position of the rear trailer axle – selecting a tight **axle spacing** in this case allows for a shorter coupling rear overhang.



Finally, **dolly drawbar length** affects the behaviour of a combination vehicle to a minor extent. Although longer dolly drawbars are preferred by some vehicle designers, when working within a restricted overall length it is better to sacrifice dolly drawbar length so that trailer wheelbase can be maximised and centre-of-gravity height can be minimised.

Couplings

As the number of articulation points in a combination vehicle increases, the on-road behaviour of the vehicle tends to degrade. A typical triple road train has five articulation points, three of which are fifth wheel (or 'turntable') couplings and two of which are tow-eye couplings.

Fifth wheel couplings are superior to tow-eye couplings because they provide a high degree of side-to-side roll limitation between the two units being connected. When fifth wheel couplings are used to connect trailers directly, such as in B-doubles (without the use of a tow-eye converter dolly), the trailers effectively 'hold each other upright' as they each experience different levels of sideways loading during on-road travel. This effect is known as 'roll-coupling' of the two vehicles. This has led to an increase in the number of 'innovative' road trains, such as this AAB-quad with a high-stability B-double trailer set at the rear. This combination has an additional trailer and an additional articulation point, but can be set up to perform more safely than a conventional triple road train.

Image courtesy of Marshall Lethlean Industries

Some operators consider it good practice to use ballrace-mounted fifth wheels in multi-combination vehicles, because the ballrace ensures free articulation between vehicles at all times. Fixed fifth wheels can sometimes lack freedom of articulation, causing converter dollies to 'bind up' momentarily and then dart to one side.

The use of double-oscillating fifth wheels and oscillating skid plates (which allow more twisting in the combination) has been proven through research to be detrimental to vehicle dynamic performance due to their reduced roll-coupling stiffness and should not be used in multi-combination vehicles.

Converter dollies

Converter dollies are considered by many to be at the root of most multi-combination vehicle dynamics problems. Their lack of roll-coupling with the preceding trailer and their tendency to be controlled by the following trailer means that their design and setup needs to be carefully considered.

'Nose-diving'

Air-suspended hinged drawbar converter dollies (particularly those with tandem axle groups) are predisposed to severe forward tilting under brakes. The braking forces between the tyres and the road, along with the force of the following trailer(s) pushing forward on the fifth wheel, act to tilt the nose of the dolly downwards. The reason for air-suspended dollies being affected more than mechanically-suspended dollies is that the vertical stiffness of a typical air suspension is around 10% of that of a typical mechanical suspension – so, for the same braking forces, the angle of tilt would be ten times greater for an air-suspended dolly. It is strongly recommended that hinged drawbar dollies with pivoting fifth wheels, with either mechanical or air suspensions, are blocked to prevent nose-diving beyond 50 to 100 mm at the front of the dolly. Some operators choose to use rigid drawbar dollies to prevent nose-diving altogether. Rigid drawbar dollies do not need to be blocked but can, however, impose high downward vertical loads on couplings. This needs to be considered in the coupling selection process.

Wear in bushes

Two occurrences commonly found to affect multi-combination vehicle dynamics are wear of the hinged drawbar bushes and wear of the tow-eye coupling mount bushes. It is important to maintain these items in good condition.

Skid plate heights and angles

Fifth wheel couplings need to be set up correctly in order to work effectively. The top of the fifth wheel surface should be level when a trailer is connected – this is governed by the manufacturer's designed coupling heights for both the towed and towing vehicles. The skid plate will not be level if the trailer is coupled to a fifth wheel at the incorrect height. If the trailer's skid plate is at an angle to the horizontal, particularly 'nose-down', unusual behaviour can result on the road.

If, for any reason, there is a need to replace or introduce another trailer into an existing combination, the designed coupling height of the trailer should be considered prior to it's use, as it is best for the skid plate to be as level as possible when connected. A 'nose-down' position is not recommended on converter dollies, as this can induce unwanted steering effects.

Nose-down inclination of the fifth wheel on level ground is not recommended

Suspension

While suspension designs can vary considerably between manufacturers, there are four features of a suspension design that contribute to the dynamic stability of a vehicle. These are:

- roll stiffness (the resistance to body roll)
- roll centre height (the height of the axis about which the body appears to roll)
- roll steer coefficient (the steer angle imposed on the axle during body roll)
- load sharing (the ability to distribute load equally between the axles in an axle group)

In general, it is desirable to maximise roll stiffness (to reduce the amount of body roll), maximise roll centre height (to reduce the amount of body roll), minimise roll steer coefficient (to improve tracking) and improve load sharing (to improve tracking). All suspensions, including drive axle suspensions, display these characteristics. It is vitally important that these parameters are controlled, especially on drive axle suspensions. Tests have shown that considerable improvements in combination dynamics can be achieved by specifying a drive axle suspension with more favourable characteristics.

Roll stiffness

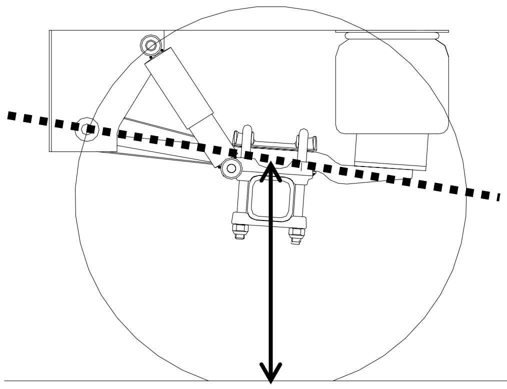
Roll stiffness is generally higher in heavy duty mechanical and air suspensions, but light duty suspensions can also have high roll stiffness. Suspension manufacturers can provide this information. For additional roll stiffness, anti-roll bars can be fitted as an option on certain suspensions.

Roll centre height and roll steer coefficient

Each individual suspension configuration has its own unique roll centre height that generally cannot be changed. For air suspensions the roll centre height is governed primarily by the height of the trailing arm pivot, while for mechanical suspensions the roll centre height is governed by the height of the spring pack contact points. Underslung suspensions typically have lower roll centre heights than overslung suspensions. Greater roll centre height is favoured as it results in reduced body roll.

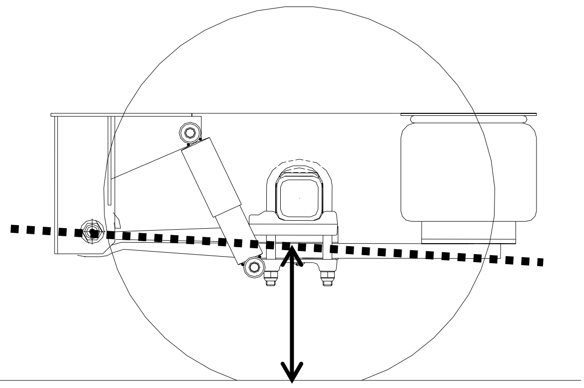
Roll steer coefficient can vary significantly between suspension designs; it depends upon the inclination angle of the suspension's roll axis. The roll axis of a suspension is not easily defined. Its orientation depends upon the type of suspension: for air suspensions it is governed by the location of compliant components, such as bushes and spring trailing arms, while for mechanical suspensions it is governed by the inclination angle of the radius rods. A more horizontal roll axis is desired. The following diagrams illustrate the differences in roll centre height and roll steer coefficient for typical suspensions. The method of estimating roll properties varies between suspension designs, so these diagrams should be used as a guide only. Consult the suspension manufacturer for specific applications.

High axis position (high roll centre)
High axis inclination (high roll steer coefficient)



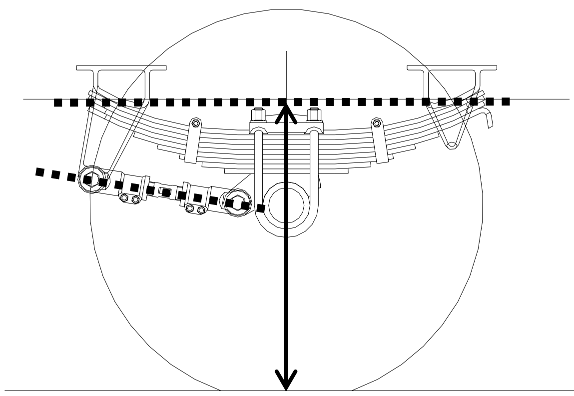
Overslung Air Suspension

Low axis position (low roll centre)
Low axis inclination (low roll steer coefficient)



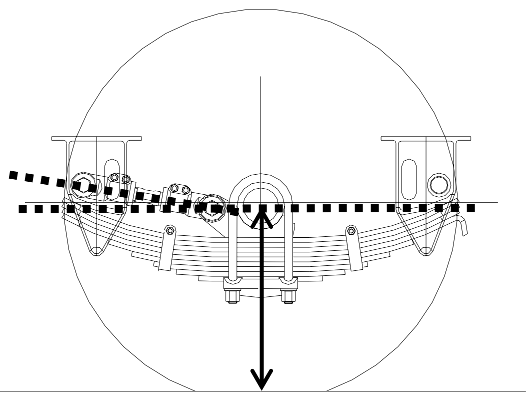
Underslung Air Suspension

High axis position (high roll centre)
High axis inclination (high roll steer coefficient)



Overslung Mechanical Suspension

Low axis position (low roll centre)
High axis inclination (high roll steer coefficient)



Underslung Mechanical Suspension

In general, suspensions with a low roll steer coefficient tend to also have a low roll centre height. These characteristics are common to underslung air suspensions, which many designers prefer to fit to converter dollies. Reasons for fitting an underslung suspension to a converter dolly include low ride height (to fit into a tight space) and low roll steer coefficient (to limit wandering when travelling over undulating roads).

Load sharing

An axle group should be set up so that each axle is operating at the same ride height. With air suspensions, if the bottom of the chassis is leaning down at the back or front of the axle group, the load sharing of the suspension is not affected (unless the suspension reaches the end of its travel – an operating condition that should never be allowed to occur). However, a 'nose-down' condition (i.e. the front axle has the lowest ride height) will generally cause poor dynamic behaviour.

An air suspension must be operated with a sufficient air supply to ensure that the correct ride height is maintained. Some air supply systems are not sufficient to inflate the airbags in a timely manner after the vehicle has been loaded, which can result in poor performance on the road.

With mechanical suspensions, it is more critical that the suspension is mounted parallel to the ground. It is important that the equalisers (rockers) are parallel to the ground when the trailer is on a level, flat surface, otherwise the suspension will not load share effectively, which can cause problems with dynamic handling.

Tyres

Tyres can have a significant impact on the tracking of a multi-combination vehicle. The construction of a tyre affects its cornering stiffness, which relates to how much it has to slip sideways in order to provide the required side force to keep the vehicle in line. Tyres must also be properly rated for the load and speed of the application.

Cornering stiffness is derived from the increase in tyre side force for a given increase in sideslip angle at a given vertical load. A tyre with high cornering stiffness will track better than a tyre with low cornering stiffness. Tyre manufacturers should be able to offer advice on which tyres perform best in this regard.

It is critical to maintain tyres by checking that they are operating at the right pressures for the prevailing loads. Inner tyres tend to be neglected at times, which increases the risk of premature wear or blow-outs as a result of being operated at very low pressures. Higher pressures are better – many operators recommend 100 – 110 psi cold inflation pressure for on-highway operation at maximum legal axle loads. Operators should consult the tyre manufacturer if they are unsure.

For more information

The intention of this Guide is to assist people involved in the design, construction and operation of multi-combination vehicles to have a greater awareness of the factors that contribute to multi-combination vehicle dynamic performance, so that these vehicles can be designed, constructed and operated in a manner that enhances safety on the road.

This Guide is not intended to cover every eventuality related to suspension performance in multi-combination use and additional advice may need to be sought for specific applications. Operators who find that they are experiencing dynamic performance problems with a vehicle should contact the suspension supplier/vehicle manufacturer(s) to ensure that the suspension is set up according to the manufacturer's specifications and to assist in seeking a solution.

It is recommended to consider the points raised in this Guide when designing a combination vehicle, or even when reconfiguring existing equipment. Speak to manufacturers about achieving the best performance from their equipment for the application at hand.

A specialist in heavy vehicle dynamics can assess the integrity of a proposed vehicle configuration at the design stage using a simulation model, or at the prototype stage through an instrumented field test.

Additional background material

It is important that designers, builders and users of multi-combination vehicles have access to the Regulations, Australian Standards, Codes of Practice, Guidelines and other publications relating to the construction and/or operation of these vehicles.

The following Regulations and publications, whilst not exhaustive, provide the necessary background material for the suspension issues that are the subject of these Guidelines.

A sound knowledge of the regulations and/or permit/notice system removes the risk of having vehicles refused registration or not being permitted to operate in multi-combination configurations.

Australian Design Rules (ADR): The design rules provide the design and construction requirement for trucks and trailers. Each new vehicle must be certified against the design rules applicable to its category and date of manufacture. The ADRs may be purchased from the ADR subscription officer at the Department of Transport and Regional Services (DOTARS) (Ph. 02 6274 7111).

Vehicle Standards Bulletin 6, National Code of Practice Heavy Vehicle Modifications (VSB6): VSB6 is essentially an in-service publication that provides valuable information on the modification of heavy vehicles. (Free download from the DOTARS website, www.dotars.gov.au).

Regulations: Each State and Territory has its own regulations modelled on the following national road transport reform regulations prepared by the National Transport Commission. Manufacturers and operators should have in their possession copies of the equivalent regulations for each of the jurisdictions in which they wish to operate the multi-combinations under consideration.

- Australian Vehicle Standards Rules 1999 (AVSR)
- Road Transport Reform Oversize and Overmass Vehicles Regulations 1995
- Road Transport Reform Mass and Loading Regulations 1995
- Road Transport Reform Restricted Access Vehicle Regulations 1995

Notices and Permits: Similarly, operators should acquaint themselves with the notices and permits that apply to the jurisdiction/s in which they wish to operate.

Australian Standards: There are many Australian Standards that apply to multi-combination vehicles. Most of these are applicable to the manufacturers of components such as suspensions and couplings and are not of direct concern to builders and users of these products.