

Dynamic load sharing on air-sprung heavy vehicles – can suspensions be made friendlier by fitting larger air lines?

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1 Introduction

The objective of this paper is to illustrate that axle-to-body forces can be altered by the application of non-standard approaches to heavy vehicle (HV) air spring plumbing. The aim of this paper is to describe the methodology and results of testing carried out on two heavy vehicles fitted with the “Haire suspension system”. In doing so, the experimental methods are described, the results are presented, analysed and extrapolated in order to illustrate the effect that the “Haire suspension system” had on changes to the peak dynamic loading, dynamic load coefficient values and load sharing coefficients at the axle-to-chassis interface. The paper goes on to discuss the possibility of reducing dynamic forces on HV suspensions by the use of this system and other methods.

The “Haire suspension system” connects the air springs on either side of a HV with larger-than-standard diameter air lines longitudinally as shown in Figure 1. The transverse air line is left as standard for fitment of the system. The manufacturers of the “Haire suspension system” have claimed that, by installation of their proprietary system, air-sprung heavy vehicle suspensions may be made “friendlier” than air-sprung HV suspensions possessing standard sized longitudinal air lines. The objective of the testing was to yield results that could be analysed to examine these claims.

The testing was performed by fitting two heavy vehicles alternately with standard longitudinal air lines and then with the “Haire suspension system” to determine differences in the dynamic suspension parameters for the two test cases as measured at the air springs.

Note that the terms air springs (more correct) and air bags (industry nomenclature) are used interchangeably in this paper.

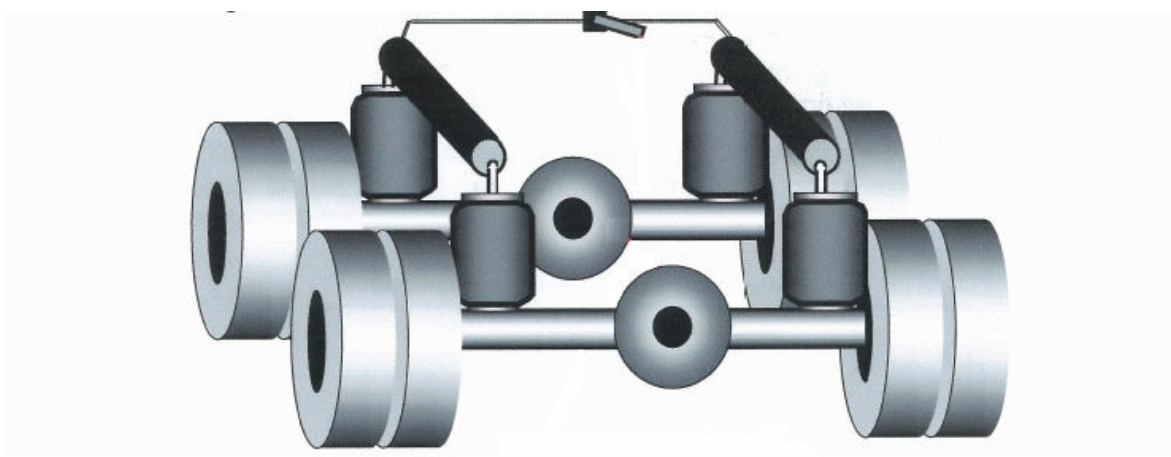


Figure 1 Schematic layout of “the Haire suspension system”. Note that some detail has been removed for clarity. Larger air lines (in black) run longitudinally and connect the air springs fore-and-aft. Transverse air line is not enlarged for this system.

2 Background

All vehicles bounce as they travel. Totally smooth roads would be nice but this is not a pragmatic expectation. Accordingly, vehicles have suspensions to compensate for the unevenness of roads. These range from the basic (where the elasticity in tyres is exploited) to the sophisticated, in the form of hydro-dynamic load compensation systems.

Broadly, HVs loaded to more than statutory mass, such as higher mass limits (HML) vehicles, are given that privilege in return for having suspensions denoted “road-friendly”. This is justified by the “conventional wisdom” mythos that trucks with road friendly suspensions (RFS) can carry greater masses and cause no greater damage than do trucks with conventional multi-leaf steel suspensions at statutory masses. Further, the transport industry is now making frequent requests for road authorities to allow heavier multi-combination vehicles (MCVs), usually with more axles, onto the network. Invariably the vehicles nominated in conjunction with these requests incorporate some form of RFS. These vehicles and their HML counterparts usually achieve that RFS status by the use of some form of air springs or “air bags”, although a small minority of conventional steel leaf-spring HV suspensions have now been certified as meeting the requirements for RFS.

The Queensland Department of Main Roads is becoming increasingly concerned that HVs with air-sprung RFS are not as sympathetic to roads as they might otherwise be. Within this judgement is the growing evidence that air-sprung RFS do not load share in the dynamic sense. That is, the mass of any axle group is not spread as evenly and as quickly as it might be when a RFS truck travels over undulations. This phenomenon creates the potential for high pavement loads under any axle that encounters a bump with respect to the others in its group.

There is no agreed testing procedure to define or measure dynamic load sharing at the national or local level. This is despite the fact that dynamic load sharing for multi-axle RFS is not a new area of research. Sweatman (1983), Mitchell & Gyenes (1989), Gyenes, Mitchell & Phillips (1994) and more recently Potter, et al (1996) have addressed the concept and have published results on comparative tests of steel vs. air and rubber suspended axle groups. Despite this, the Australian specification for RFS, VSB-11 (Department of Transport and Regional Services, 2004), nominates only that RFS suspensions must have static load sharing, to a defined value, “between axles in the axle group”. Further, it does not define a methodology to determine that static load sharing value.

Davis and Sack (2004) performed testing in Feb '03 which indicated that RFS do not load share dynamically when in multi-axle groups. This work was on a semi-trailer fitted with standard longitudinal air lines (6.5mm inside diameter, 9.5mm outside diameter). The results showed that the transfer of air between air springs on the test vehicle was in the order of 3 S.

3 Experimental procedure

3.1 General

Two HVs were used for the testing. They were a tri-axle semi-trailer towed with a prime mover fitted with a tridem (2 drives, one pusher axle) drive group; and a tri-drive rigid chassis truck. The suspensions of the semi-trailer tri-axle group, the tridem drive group of the prime mover and the drive group of the rigid truck were air-sprung.

The air springs (air bags) were configured such that they could be connected using either standard longitudinal air lines or larger-than-industry-standard longitudinal air lines denoted the “Haire suspension system”. Photos of the test vehicles are shown in Figures 2 & 3.

The tests comprised driving the HVs over a series of test bumps at increasing and defined speeds with standard longitudinal air lines installed. The standard longitudinal air lines between the air springs were then disconnected and the “Haire suspension system” installed. The HVs were then driven over the same test bumps at the same set of speeds as the previous tests. The dynamic signals at each air spring of the HVs under test were measured and recorded for the two test cases (i.e. standard longitudinal air lines vs. the “Haire suspension system”).

3.2 Procedural detail

The prime mover/semi-trailer test vehicle was loaded with a fixed payload (a shipping container). Static mass per axle was approximately 6½t for all air-sprung axles. The load on this test vehicle was not altered during the tests. The spacing between centres from the prime-mover’s pusher axle to the middle axle of the tridem drive group was 1.170m. The spacing between centres from the middle axle to the rear axle of the tridem was 1.255m. The distance between centres of the semi-trailer tri-axle group was 1.365m.



Figure 2 Side view of prime mover and semi-trailer test vehicle during testing



Figure 3 Side/front view of rigid chassis test vehicle

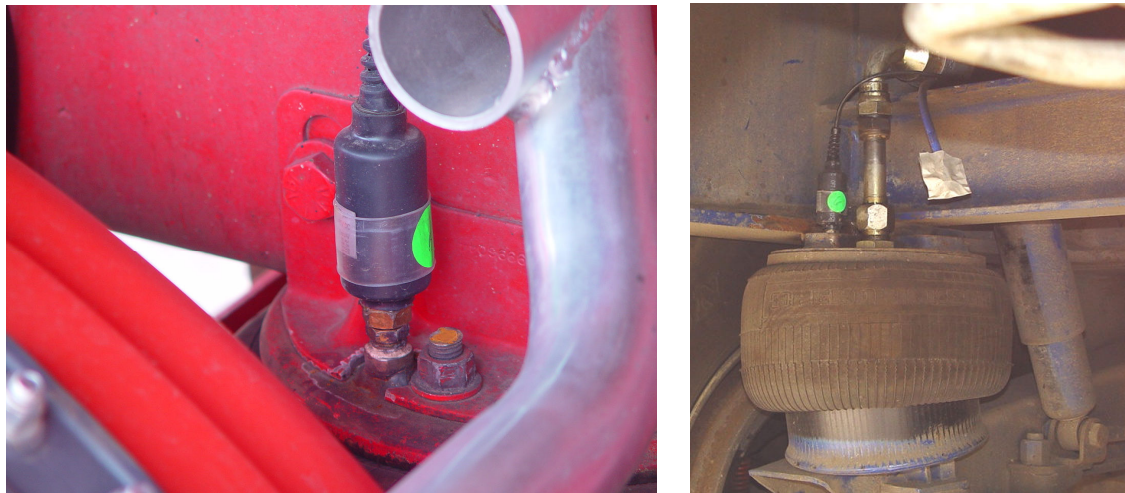


Figure 4 Pressure transducers (green stickers) used to measure dynamic loadings in the air bags of the test vehicles

The tri-drive rigid truck was used with its fixed payload on it (i.e. a drilling rig). The load on this test vehicle could not be altered during the tests. Static mass per drive axle was approximately 6t. The axle spacing of the tri-drive group on the rigid truck was 1.30m between centres.

Test equipment was fitted to the trucks in the form of an air pressure transducer (Figure 4) on each air bag (i.e. 2 per air-sprung axle) and a proprietary instrumentation (TRAMANCO CHEK-WAY[®]) system.

The dynamic loads on each air bag were measured off the air pressure (proportional to the force between the axle and the chassis) in each air bag and recorded as the HVs negotiated the test bumps. This resulted in test data in the form of a time-series signal of the pressure in each air bag of each HV for the two test cases at the test speeds.

An advanced version of the TRAMANCO on-board CHEK-WAY[®] mass measurement system was used to measure and record the dynamic loads on each air bag, via the pressure transducer outputs, as the combination was driven over a series of test bumps. The system sampling rate was 41.66Hz giving a sample interval of 24.0mS. Note that the natural frequency of a typical heavy vehicle axle is 10 - 15Hz (Cebon, 1999) compared with a relatively low 2 - 3Hz for sprung mass frequency (de Pont, 1999).

Any attempt to measure relatively higher frequencies (such as axle-hop) using time-based recording will necessarily involve a greater sampling rate than when relatively lower frequencies (such as the sprung mass frequency) are to be determined (Chesmond, 1982). Since axle-hop was the highest frequency of interest for the analysis undertaken, the 41.66Hz sampling frequency used by the CHEK-WAY[®] system was adequate to capture the test signal data, since 41.66Hz is higher than twice any axle-hop frequency. Hence, the Nyquist sampling criterion (Shannon's theorem) was met. Note that the CHEK-WAY[®] system is subject to Australian Patent Application number PCT/AU200/001107 and International Patent Application number 2004264997.

Test bumps were installed within the road test length (Figure 5) with appropriate traffic control.



Figure 5 Showing the installation of the test bumps

The test bumps were made of recycled rubber with a deflection of 2mm in 50mm (i.e. 4%) with an applied static wheel load of 8.25t. The choice of recycled rubber simplified fastening to the road curvature. 3 off test bumps 25mm high x 300mm wide & 3m long; and 2 off test bumps 50mm high x 300mm wide & 3m long were used. The test bumps were spaced in integer multiples of the pitch (axle spacing) of the axle group of interest.

The configuration of the test bumps (height & spacing) was as follows, for the direction of travel of the test vehicle: 25mm; 25mm; space; 50mm; space; 50mm; 25mm or diagrammatically as shown in Figure 6.

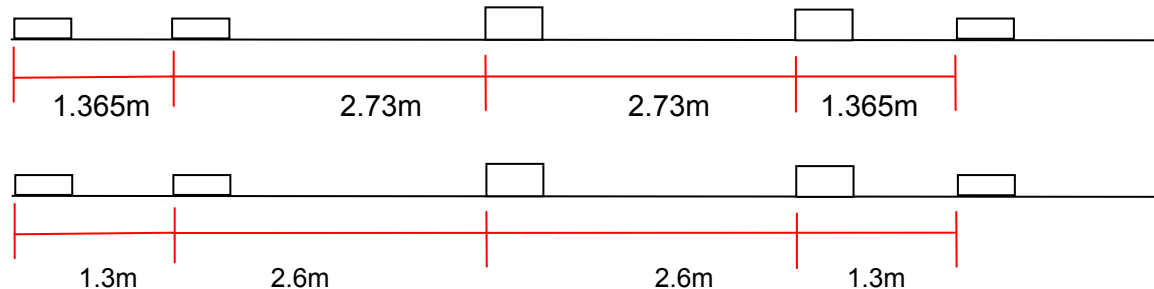


Figure 6 Test bump spacing and layout for the prime-mover/semi trailer (above) and for the rigid truck (below). Direction of travel for testing was L to R relative to this diagram.

To test a suspension in the dynamic sense the axles need to be exercised in the vertical direction. However, exciting them in only the upwards direction will yield results for only one direction in that degree of freedom. In reality, potholes, dips and undulations resulting in downward movement of an axle are part of the environment of a working truck. Accordingly, the arrangement of test bumps used for the testing forced downward travel as well as upward travel using a “tri-state” sequence. The position in which any axle was placed with respect to the others in its group when it was on any of the 25mm bumps used in the test arrangement was considered to be neutral or “without disturbance”. This was considered a zero datum (first state). The spaces between the test bumps (or absence of bump) then represented a 25mm pothole or trench in the road surface (-1 w.r.t datum, “down” or second state) and the 50mm bumps represented a 25mm vertical rise (bump) in the road surface (+1 w.r.t. datum, “up” or third state).

The maximum amount of load sharing required by a suspension occurs when two axles undergo excursions in opposite directions simultaneously (i.e. out-of-phase). The tests described herein were designed specifically to exercise a tri-axle group with out-of-phase stimulus. Considering any axle in a tri-axle group under these conditions, it can be neutral (0), up (+1) or down (-1). Using the “spaces” occurring at the relevant pitch before and after the first and last test bumps resulted in the described configuration of test bumps providing 8 of the possible 12 up/down/neutral combinations for a tri-axle group.

The state of the drive axles in Figure 7, for example, then became (L to R) -1; 0; 0 or down; neutral; neutral.

For the rigid truck, the spacing was in integer multiples of 1.30m. The prime mover's tridem pitch was not equi-spaced, preventing out-of-phase excitation as described above. However, the drive group was instrumented, tested and its results analysed. This was to understand more completely the effect of installing the "Haire suspension system" on axle groups similar to the non-equi-spaced tridem on the prime-mover, should such axle groups be subjected to the stimulus of the bumps as configured. It was postulated that this would provide insights to the behaviour of such groups with in-phase (common-mode), random and/or chaotic forces present. To get the maximum excitation from each axle under test for the prime-mover trailer combination (as described above), the trailer group pitch was chosen for the bump spacing of the tests for the prime-mover/semi-trailer accordingly. Hence the integer multiples of the pitch of the test bumps for the semi-trailer/prime mover test was 1.365m

The tests were performed at 1 km/h, 5 km/h, 10 km/h, 20 km/h & 40 km/h. Given that the testing environment was a public road, the testing was limited to 40km/h so that the test vehicles were kept to within their controllable limits.

4 Results and analysis

4.1 General

The analysis utilised the methods for deriving dynamic wheel-force parameters (e.g. DLC, LSC, etc) but applied these methods to the forces on each air bag (i.e. between the body and the axle). That is, the forces on the air springs were used as a surrogate for wheel forces in the formulae for the various dynamic measures such as DLC and LSC. This was in order to derive measures for body-to-axle dynamic parameters and alterations to them, if any, due to the fitment of the "Haire suspension system". The values and analysis in the following section show the results derived from the test HVs for peak loading, dynamic load coefficient and load sharing coefficient performed using the measurements off each air bag for the different test speeds and for the two cases of size of longitudinal air line used in the tests.



Figure 7 Showing rigid truck travelling over test bumps. Note that test bump spacing is at the pitch of the axle group

If wheel-load values for DLC, LSC, etc were to be derived from these tests then the inertia of the unsprung mass of the axles and the wheels would need to be taken into account. The aim of these tests was to determine whether the fitment of the “Haire suspension system” altered the dynamic forces between the axles and the body of the test vehicles and the proportion of that change when compared to an air-suspended HV with standard longitudinal air lines. The test procedure altered only the size of the longitudinal air lines. The alteration in dynamic parameters for the two cases was derived as a ratio or factor of reduction as shown below.

Both the sets of results for the semi-trailer axle group and the rigid truck drive group were derived during out-of-phase activity. That is, for one axle climbing up and travelling over a test bump at the same time as another axle climbing off and down another test bump and/or the third axle climbing, staying at the same level or descending for the testing rationale as described above. This was not the case for the prime-mover tridem drive group as previously explained.

The only alteration to the two test vehicles was the size of the longitudinal air lines. In particular, the inertia of the unsprung mass was the same for the two test cases (i.e. standard longitudinal air lines vs. the “Haire suspension system”) and so was the tyre elasticity. On this basis, whilst it is not strictly correct to say that wheels loads were measured, any alterations to them from the fitment of the “Haire suspension system” may be inferred from the results below.

An example of the plot of only one trace of test data for one side of one axle (i.e. one air spring) is shown in Fig 8. A summary of the results of changes to all the dynamic parameters, because of fitment of the “Haire suspension system”, is shown in the Executive Summary and in the Conclusion.

Figure 8 shows an example of data for 40km/h testing. This illustration of the test trace is not intended to show any difference in the operation of “the Haire system” vs. standard sized longitudinal air lines in the time domain. The test traces are displaced on the time axis for clarity only. The intent of showing this example is to illustrate the difference in the magnitude of the measured signals (proportional to dynamic forces) at the air springs of the HV under test and to show typical data measured during testing.

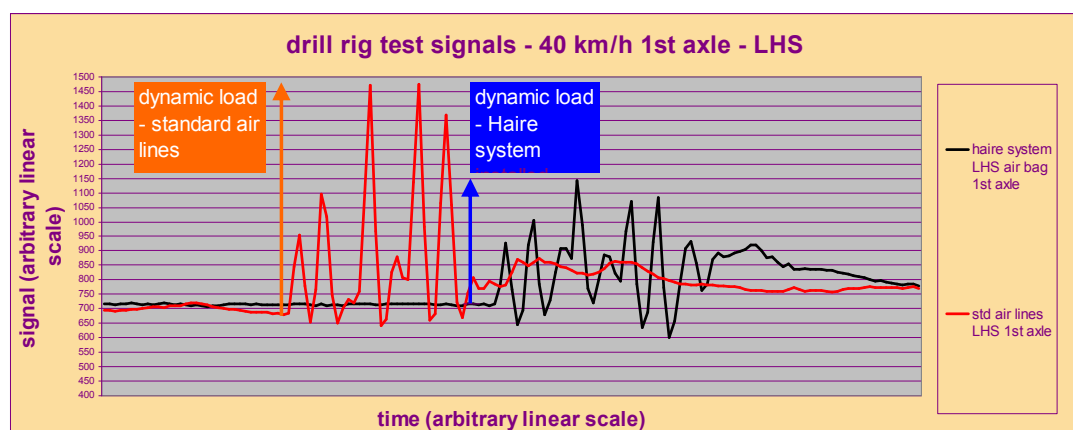


Figure 8 Example of test trace showing difference in the signals for the case of standard longitudinal air lines and for the case of fitment of the “Haire system”

4.2 Dynamic load ratio (DLR)

A variable denoted the dynamic load ratio (DLR) was derived. This was defined as the ratio of the values of peak dynamic loading (over and above any steady-state load) when comparing the two test cases, i.e. standard longitudinal air lines vs. the “Haire suspension system”. Mathematically this ratio was defined as follows:

$$\text{DLR} = \frac{\text{net dynamic load ("Haire system" installed)}}{\text{net dynamic load (standard longitudinal air lines installed)}}$$

A pictorial description of these (net) dynamic values can be seen in Figure 8.

The DLR was derived by finding the ratio of net dynamic loads (peak dynamic value less steady-state value) for the two test cases, that is: the Haire suspension system compared with standard air line configuration, at each air spring for the two HVs tested.

Figure 9 shows this ratio in graphical representation as derived, for each test speed and for each air bag, for the data averaged across all air bags for the two test cases at the test speeds for the tri-axle semi-trailer axle group. This was derived by plotting the DLR averaged over all air bags for the test speeds for each test case. The best regression line was found for each test case noting the formula and R^2 value thereof. Using this formula, extrapolation of values to 100km/h was performed, preserving or improving the R^2 value from the original 1 - 40km/h data. Note also the regression line, asymptotic to 0.77 at 100km/h, for the extrapolated data. Similar plots were derived for the tridem drive group of the prime mover and the tri-drive group of the rigid truck.

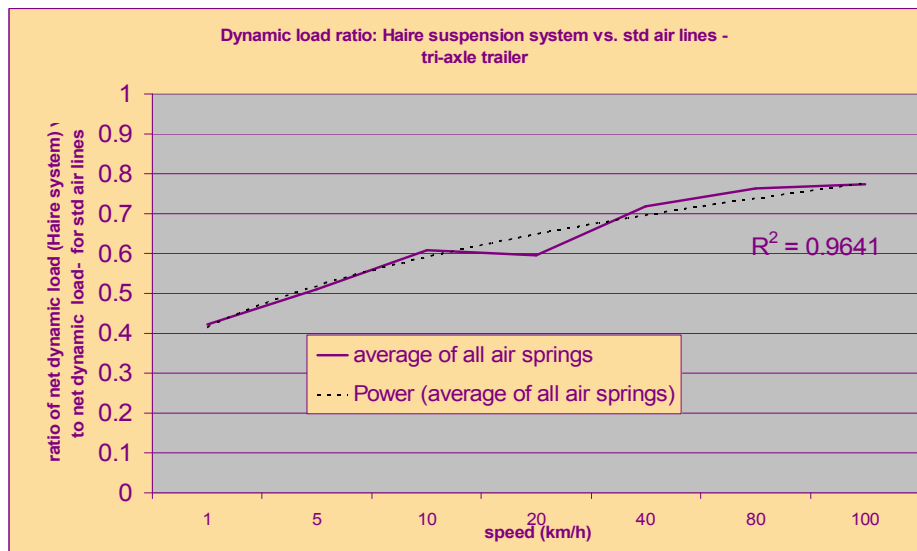


Figure 9 Relationship between test speed and dynamic load ratio (DLR) for the tri-axle semi-trailer group

4.3 Alteration to dynamic load coefficient (DLC)

Figure 10 shows the DLC results for the test data averaged across all air bags for the two test cases at the test speeds for the tridem drive group of the prime mover. This was derived by plotting the DLC averaged over all air bags for the test speeds and for each test case. The best regression line was found for each test case noting the formula and R^2 value thereof. Using this formula, extrapolation of values to 100km/h was performed, preserving or improving the R^2 value from the original 1 - 40km/h data. Similar plots were derived for the tri-axle group of the semi-trailer and the rigid truck tri-drive group.

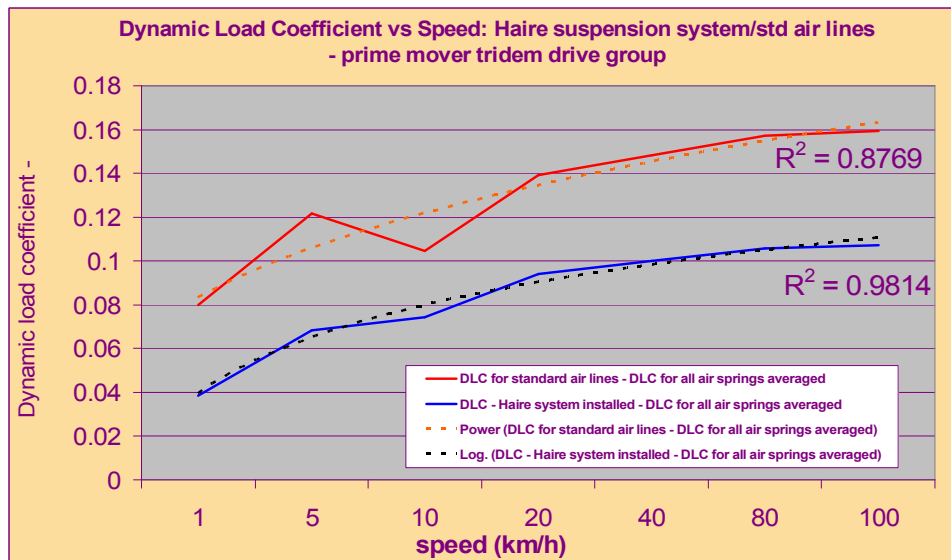


Figure 10 Relationship between test speed (& extrapolations) and the dynamic load coefficient (DLC) for the tridem drive group of the prime mover

4.4 Alteration to the load sharing coefficient (LSC)

Figure 11 shows the LSC for the test results averaged across all air bags for the two test cases at the test speeds for the tri-drive group of the rigid truck. This was derived by plotting the LSC averaged over all air bags for each test case at the test speeds. The best regression line was found for each test case noting the formula and R^2 value thereof. Using this formula, extrapolation of values to 100km/h was performed, preserving or improving the R^2 value from the original 1 - 40km/h data. Similar plots were derived for the tridem group of the prime mover and the tri-axle group of the semi-trailer.

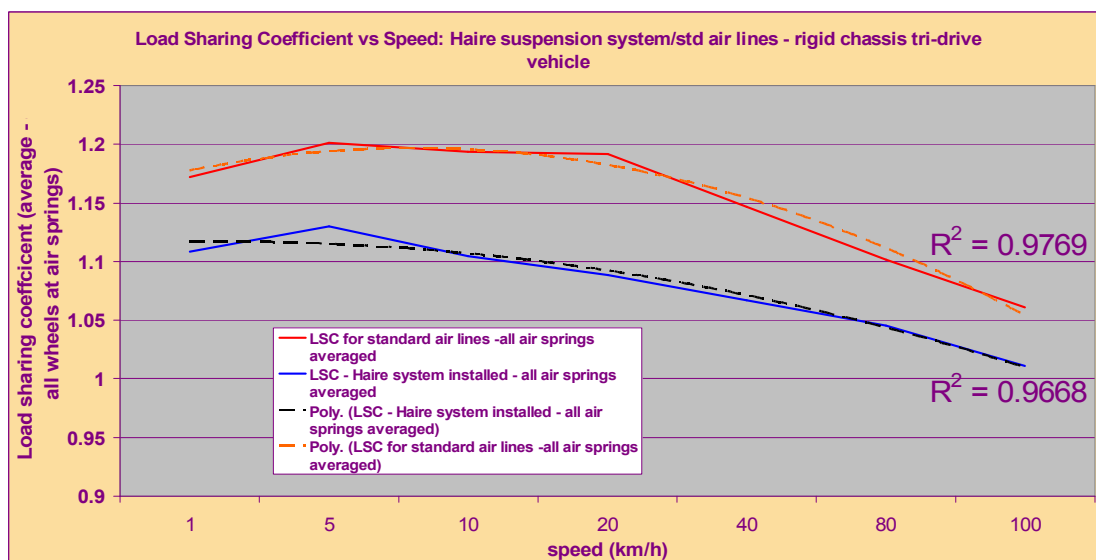


Figure 11 Relationship between test speed (& extrapolations) and load sharing coefficient (LSC) for the tri-drive group of the rigid truck

Table 1 Alteration in dynamic forces due to fitment of the “Haire suspension system”

Vehicle/ axle group	Alteration in dynamic force at air springs as extrapolated to 100km/h		
	Dynamic load coefficient	Dynamic load ratio	Load sharing coefficient
Tri-drive group on rigid truck	-58%	-50%	-19%
Prime mover tridem drive group	-33%	-3%	0.9% increase
Semi-trailer tri-axle group	-19%	-23%	-0.3%

4.5 Summary of results

By extrapolation to highway speeds, the indicative reductions in dynamic parameters when the “Haire suspension system” was fitted were derived as shown in Table 1, except as noted. It is for noting that the extrapolation to 100km/h of the LSC value for the tridem drive group of the prime mover was not particularly successful; relatively high R^2 values were not achievable. The R^2 value for the LSC results for the tridem was particularly sensitive to the algorithms used to generate the extrapolations, making conclusions regarding the validity of this measure difficult. This may have been due to the common-mode, chaotic or random nature of the test bump signals as they applied to the non-equispaced axles of the drive group.

5 Discussion

The introduction into Australia of HVs with RFS in the ‘80s and ‘90s was predicated on the basis that, whilst RFS trucks at HML loadings may damage bridges more than trucks with conventional multi-leaf steel suspensions at statutory mass, pavements and surfacings would be less stressed by the higher loads because of the supposed “friendliness” of air-sprung suspensions. Accordingly, road authorities allowed an increase in the mass on axles and axle groups. The philosophy was that some balance would be achieved, therefore, and that the damage that HVs at higher mass loadings would cause would turn out to be neutral (OECD, 1998). Despite this, the DIVINE technical report (OECD, 1998, pp 77) states (this author’s italics):

“When air-suspended vehicles travelled at critical speeds over axle-hop inducing features, large dynamic responses and multiple fatigue cycles were observed. These responses were up to 4.5 times the dynamic load allowance specified in bridge design. Where axle hop was not induced, the dynamic response was much smaller. A probable explanation for this is the fact that the *very limited dynamic load sharing* in air suspensions allows the axles in a group to vibrate in phase at axle-hop frequencies. ‘Crosstalk’ between conventional steel leaf suspensions limits this possibility.”

Pesterev, Bergman & Tan (2003) clarified the colloquialism ‘crosstalk’ used in the quote from the DIVINE report and explained the meaning and use of this term to be “code” for dynamic load sharing.

The RFS work in Europe (Potter, Cebon & Cole, 1997; Mitchell, & Gyenes, 1989) and Australia (Sweatman, 1983) was used to support the argument for air-sprung RFS HVs carrying greater mass in Australia and elsewhere.

Ian Simmons, Head of Vehicle Technology at the Transport Research Laboratory Ltd in Wokingham, worked on much of the original testing (e.g. Mitchell, & Gyenes, 1989). Mr. Simmons has stated subsequently that the testing of air-sprung vehicles was performed with various longitudinal air pipe sizes between 8mm and 12mm, outside diameter. Mr. Simmons has subsequently gone on to say, “these pipe sizes will not provide dynamic equalisation as there will not be sufficient transfer between displacers [air bags]”, (Simmons 2005). Note that the industry standard polyamide air line in Australia has a 9.5mm (nominally 10mm) outside diameter and a 6.5mm inside diameter.

Review of the original research has indicated, as shown above, that dynamic load sharing was not a feature of air suspensions and used vehicles with longitudinal air lines slightly larger than those used subsequently in Australia when RFS fit-out occurred on the Australian transport fleet. It is of concern that this research showed that air-sprung HV suspensions were not load sharing in the dynamic sense but that the Australian HV fleet was equipped with these small air lines on their RFS anyway. Therefore, the dynamic forces on the vehicles, pavement and surfacings have not been and are not being equalised as well as they might be, given the increase in axle forces from HVs with higher masses as these vehicles travel over typical, uneven roads. This means that since the introduction of air-sprung RFS HVs to Australia, the fundamental element of air-sprung RFS design in the form of small air lines has been placing HVs and the road asset under greater stress than if adequate load sharing were implemented. Further, HVs have been designed to withstand unnecessarily high dynamic loads compared with the case where better dynamic load sharing might have been implemented.

The test results for the HVs described herein and review of the original research into air-sprung HV suspensions indicates strongly that small longitudinal air lines on RFS do not provide as much reduction of dynamic forces as would suspensions fitted with larger longitudinal air lines. This is not to discount other forms of making air suspensions friendlier to by the use of accumulators (registers or “ping tanks”) attached to the air lines.

The reality for the Australian transport industry is that air-sprung HVs at higher masses than statutory loading are operating over a significant portion of the transport network. Large numbers of these HVs are equipped with small longitudinal air lines between their air springs. Further, the clock cannot be turned back. There is, however, potential for savings on HV suspensions, structures, surfacings and pavement maintenance by greater emphasis and specification of the dynamic response (particularly the load sharing ability) of RFS.

The results herein indicate that use of larger longitudinal air lines would result in the reduction in dynamic forces imparted to the test HV from road unevenness. Reduction in dynamic forces imparted to the HV where such systems are installed should allow lighter and more economical suspension and chassis components. The design forces would be lower with larger longitudinal air lines when compared to those present in air-sprung RFS where standard longitudinal air lines were used. If applied to the HV fleet, this would logically lead to HVs with reduced tare, lower cost chassis and suspensions leading to increased payloads without overall increases in GVM.

It is noted that in some recent trends, HV manufacturers have recognised the inadequacy of RFS to load share dynamically and have moved to rectify it. Kenworth’s T350 Agitator (Willox, 2006) refers to the use of “one-inch air line connections” providing “rapid response” and “better load sharing ability” when load sharing is required. Further evidence of the HV manufacturing industry moving toward better load sharing for air

suspensions can be seen in Figures 12 & 13. Figure 12 shows details of two Kenworth K104 chassis. Note the larger-than-standard air lines emerging from the tops of the air bags and the larger-than-industry standard longitudinal air pipes between the air springs (green arrow, Figure 13). This measure by Kenworth in the original equipment market and the efforts of operators who have sought other solutions, such as the “Haire suspension system” (Estill, et al, 2000), in the after-market arena, indicate that better dynamic behaviour from air-sprung HVs is available (and desired by operators).

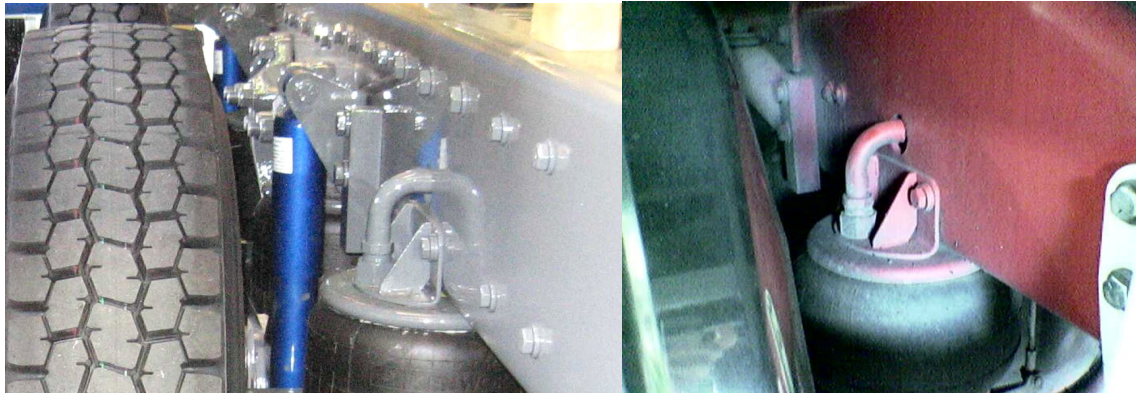


Figure 12 Detail of 2 Kenworth K104 chassis. Note the larger-than-standard air lines fitted to the air springs on these units



Figure 13 Another detail of the LHS Kenworth K104 chassis in Figure 12. Note larger-than-standard longitudinal air line (arrowed in green) and standard-sized transverse air line (blue arrow)

Newton’s 3rd Law states: “For every action, there is an equal and opposite reaction.” Reduced dynamic loads up into the axle-to-chassis connection should lead to reduced dynamic loads down to the road surface and pavement. Any such measure should assist in reducing the increasingly rapid consumption of the road network asset from heavier loads being demanded by transport operators.

Further work is currently underway on the effects of fitment of larger longitudinal air lines on vehicle stability parameters, in particular any lateral stability metrics. This will be in the form of a computer model that will be calibrated using the results of the testing described in this paper. This model will also include wheel forces with a view to determining any changes due to the fitment of larger longitudinal air lines to wheel-load DLC, LSC, etc at highway speeds.

6 Conclusion

Analysis of the data from these tests indicates that reductions in dynamic factors at the axle-to-body interface are available. With the exception of the LSC on the semi-trailer and the tridem drive group on the prime mover all the dynamic load factors derived from the analysis of the test data for the HVs tested showed distinct improvements for the case where the “Haire suspension system” was fitted compared with standard longitudinal air lines. Implied within this finding is that the “Haire suspension system” achieves reductions in dynamic parameters by allowing better response to dynamic loads than that afforded by air suspensions with conventional longitudinal air lines. This confirms the anecdotal information from operators who have fitted this system and the reports (Estill, et al, 2000) of successful results from fitment of this system.

It is recommended that HV manufacturers review the results of the outcomes from the testing described in this paper (and Kenworth’s approach in fitting larger longitudinal air lines) and examine whether significant economies in suspension componentry could be brought about by the provision of larger longitudinal air pipes on air-sprung RFS. The analysis herein indicates strongly that reduction of shock loads and other dynamic effects is available via these measures. Whilst not explored herein in a quantitative sense, it is suggested that the use of accumulators (ping tanks) would also have a mitigating effect on HV dynamic loadings.

HV manufacturers should be encouraged to consider the benefits of reductions in dynamic forces either by fitment of systems similar to the “Haire suspension system” or that implemented by Kenworth. An increase the size of the longitudinal airlines in multi-axle groups or the installation of “ping tanks” on the air lines of air-sprung RFS HVs could lead to more payload, reduced shock loads to delicate payloads and cheaper chassis componentry.

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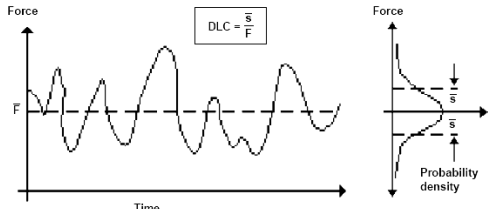
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8 Appendix 1 – glossary

Terms, abbreviations and acronyms	Meaning
Dynamic Load Coefficient (DLC)	<p>Coefficient of variation of dynamic tyre force. It is obtained by calculating the ratio of the root-mean-square (RMS) of the dynamic wheel forces (std dev. Of F in diagram below) divided by the static wheel force, i.e. the coefficient of variation of the total wheel load. A perfect suspension would have a DLC of 0. The range in reality is somewhere between 0 and 0.4 (Mitchell & Gyenes, 1989).</p> <p>Figure II.1. Definition of Dynamic Load Coefficient (DLC) (OECD, 1992)</p>  <p>Source: OECD Road Transport Research, 1992.</p>

Terms, abbreviations and acronyms	Meaning
DLR	Dynamic load ratio. The ratio of the values of peak dynamic loadings (over and above any steady-state load) when comparing the two test cases.
Dynamic load sharing	Equalisation of the axle group load across all wheels/axles under typical travel conditions of a HV (i.e. in the dynamic sense).
HML	Higher Mass Limits. HML vehicles are allowed to carry more mass (payload) in return for their suspension configuration being “road friendly”. This usually means that their suspensions incorporate air bag technology.
HV	Heavy Vehicle
LSC	<p>Load sharing coefficient – a measure of how well a suspension group equalises the total axle group load. This is a value which shows how well the forces of a multi-axle group are distributed over each tyre &/or wheel in that group: Potter, Collop, Cole & Cebon (1994).</p> $LSC = \frac{\text{Mean force of tyre (i)}}{\text{Nominal static tyre force}}$
R ²	R squared is a value assigned to a statistical regression model to show its predictive power and has a numerical value assigned to it between 0 and 1. The closer R ² is to one, the better the predictive behaviour of the model. A value of R squared equal to one occurs when the regression is aligned perfectly with the actual results.