Stability and on-road performance of multi-combination vehicles with air suspension systems project

Overarching Report

Prepared for the Remote Areas Group

Department for Planning and Infrastructure

Roaduser Systems Pty Ltd

January 2005

Project Information

This Overarching Report covers all the projects completed thus far in the investigation of air suspension behaviour in multi-combination vehicles. These projects can be divided into two main project streams, the field survey conducted by Estill and Associates Pty Ltd and the *Principal Project*. For a graphical representation of project and sub-project relationships, please refer to Appendix D and Appendix E.

The *Principal P*roject is based on the terms of reference entitled, ‘Stability and On-Road Performance of Multi-Combination Vehicles With Air Suspension Systems’ agreed to at the Dubbo meeting of the Remote Areas Group (RAG) that was held on the 19th February 2001. (Refer Appendix B). The *Principal Project* comprises a computer simulation study (Stage 1), road train trials (Stage 2) and the development of a set of trailer construction guidelines (Stage 3). Stage 3 is currently in progress and is not a subject of this report.

This report places the individual reports in some rudimentary historical context and summarises the major findings and observations in a single document.

The release of the field survey and project reports is intended to further advance the knowledge base of the performance of heavily laden, high centre of gravity multi-combination vehicles.

Overarching Report

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Preface:

Background

The publication of this report marks the end of a long and complex project involving the hard work and generosity of many people both in government and the road transport industry.

For many years both heavy vehicle operators and drivers have raised concerns about the performance of heavily loaded, air suspended long combination vehicles. These concerns have included problems with vehicle handling and in some extreme cases, vehicle roll-overs.

The main objective of the project from its very outset has been to gain a better understanding of the undesirable behaviours of certain road train combinations in an attempt to provide practical solutions to either reduce, or eliminate the cause of these behaviours.

I am pleased to report that as a result of the investigations undertaken the influence of suspension type on the performance of heavy vehicles, and in particular long vehicle combinations that are heavily loaded with high centre of gravity loads, is now better understood at a more scientific level. We now have the foundation for further research into the behaviour of these large vehicles with the potential to improve both productivity and safety.

The information gathered may also have some useful applications in assisting the Performance Based Standards (PBS) project currently being undertaken by the NTC. The findings have been forwarded to the NTC PBS project team for information and review as necessary in relation to vehicle performance measures for certain types of multi-combination vehicles.

The next stage of this project involves the use of this knowledge in the preparation of guidelines to assist both operators and trailer manufacturers in specifying heavy trailers intended for long multi-combination use. The fundamental purpose of the guidelines is to ensure that future trailers have improved handling characteristics when used in heavy applications, thus improving road safety generally. (The National Transport Commission (NTC) has provided funding to assist the Australian Road Transport Suppliers Association (ARTSA) to commence production of the guidelines. The guidelines when completed will be available for download free of charge from the ARTSA website.)

Further information

To assist those who may not be familiar with all of the performance indicators that appear in the reports, the most significant of these are explained in Appendix A. A brief description of how they are measured and/or determined is also included.

ARTSA, with the assistance of the NTC, produced a very well illustrated publication titled *PBS Explained* that provides a comprehensive summary of all the current PBS measures. This document is available for free download on the ARTSA website, www.artsa.com.au. (Figure A2 - Rearward Amplification, in Appendix A was provided courtesy of ARTSA.)

Acknowledgements

A significant number of people have been involved in this project since its inception in 1999 and appreciation of their involvement is recognized in the Acknowledgments in Appendix C.

My personal direct involvement began with the commencement of the Principal Project and therefore my acknowledgements on behalf of the Project Management Teams lie with this stage of the Overarching Project.

This project was deemed to be important by the Remote Areas Group (RAG) members and this was emphatically demonstrated by members at the "Dubbo' meeting. (Refer to Item 8.3.6 for a list of those who attended that meeting). The RAG chairman at that time, Howard Croxon, strongly supported the views of RAG and has remained a strong and loyal supporter of the project to this day.

Members of the WA Remote Areas Focus Group together with other industry members have been particularly supportive of the project and assisted greatly by providing both moral and financial support. Their support was no better demonstrated than during the combined road train trials held in April 2004 when industry members (Mr John Mitchell and Mr John Leeds) provided vehicles, drivers and their own time to enable the on-road testing to proceed.

Both the senior management and staff at Roaduser Systems Pty Ltd have been extremely co-operative and have invested a great deal of time and effort in progressing the scientific investigation phase of the project. Dr Peter Sweatman and more recently, Mr Rob Di Cristiforo's involvement has been extremely professional and it has been a pleasure to have them involved in this project.

It is worth noting that Dr Sweatman has publicly noted that the combined road train trials which included the on-road testing of the triple road train combinations for this project, along with the testing of two innovative vehicle combinations for Queensland Transport and a series of braking tests for Main Roads (WA), was the largest and most successful on-road testing program conducted in Australia thus far.

Main Roads (WA) contributed significantly in financing the Stage 2 project and in covering the costs of road closures and road management necessary to allow the on-road instrumented testing to take place. To this end we are grateful to Des Snook and his team for their support as the Stage 2 project would never have commenced without the financial assistance of Main Roads (WA). The assistance of Les Bruzsa and his team from Queensland Transport also needs to be acknowledged for freely offering their expertise and time in the instrumentation of vehicles for all segments of the combined road train trials.

The assistance of the NTC in progressing the Principal Project has been critical to its success and to this end the support of its Chief Executive, Mr Tony Wilson has been very much appreciated.

A special note of thanks also to Albert O'Neill (Estill), Ian Tarling, John Hollins (NT) and Les Bruzsa (Qld) who have acted as advisors throughout the Principal Project.

Finally I need to thank the members of the project management teams that have worked closely with me throughout the project over the past four years. Barry Hendry (NTC) who has carried much of the administrative burden and Rex Middleton (DPI (WA)) who has often had the tedious task of reviewing the many versions of the reports and documents.

To all involved, my sincere thanks.

J S Dombrose
Project Manager

Vehicle Safety Branch
Department for Planning and Infrastructure (WA)

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Overarching Report
Stability and on-road performance of multi-combination vehicles with air suspension systems project

1 Executive Summary

The primary areas of concern identified by Estill related to long multi-combination vehicles with air suspension systems that typically operate at high mass limits with high centre of gravity loads. There was also strong anecdotal evidence that air suspension modifications on some vehicles were being undertaken to counteract some of the reported undesirable behaviours.

Reported undesirable behaviours included increased roll, sway and lurch of the vehicle making it difficult for the driver to control the combination. Drivers also reported that air sprung prime movers had a tendency to follow road indentations requiring a greater steering effort to keep the vehicle on its intended path. Air suspended dollies were reported to increase roll, reduce stability and behave erratically under heavy braking.

As a result, drivers reported a preference for spring dollies that they felt were safer and considered their use resulted in a combination that was much easier to control.

The survey conducted by Estill, provided sufficient anecdotal evidence to make it apparent that guidelines for the use of air suspension systems in multi combination vehicles would be a positive safety initiative and of assistance to both manufacturers and operators alike. As a result RAG was of the view that this issue needed to be examined and researched more thoroughly before meaningful guidelines could be prepared.

To this end, Roaduser were engaged to carry out Stage 1 of the project that entailed carrying out desktop computer simulations on a variety of heavy vehicle combinations.

As part of the project, Roaduser made considerable refinements to its computer modelling simulation to reproduce more closely the behaviour of air suspensions. This resulted in the determination that the air suspensions were not as stiff as previously thought.

The refined model revealed that air suspended multi combinations are very sensitive to steering inputs from the driver. These findings align closely with driver's anecdotal evidence of how these vehicles behave.

There was some strong feeling amongst certain RAG members, which was strongly supported by the project manager, that the theoretical computer simulations should be validated by physical instrumented testing of multi-combinations. This in turn led to the engagement of Roaduser to conduct Stage 2 of the principal project, that entailed a series of instrumented tests on triple trailer road trains carrying livestock. Three types of road train combinations were tested; air suspensions on all trailers, air suspended trailers with steel suspended dollies and an all steel suspension combination.

1.1 Summary of Significant Findings and Observations

The evidence gathered during the Stage 2 project field trials verified the findings of the Stage 1, simulations. This in turn resulted in a greater level of confidence in the ability of computer simulation techniques to determine and predict real life performance of heavy combination vehicles.

The simulation program used in Stage 1 and Stage 2 also proved to be reliable in predicting the performance of innovative vehicles and is therefore not limited to the assessment of standard road train configurations.

The results are consistent with driver and operator experience.

A scientific explanation is now available as to why fully air suspended long and heavy combination vehicles with a high centre of gravity are relatively more difficult to drive compared to other vehicles.

The extremely good results obtained from the innovative vehicles tested indicate that there is a great potential for the increased use of innovative vehicles in the transportation of goods such as livestock which could deliver higher productivity with increased road safety.

This increased level of confidence in the results of the computer simulations, particularly across a wide range of multi-combinations, has the advantage of providing greater comfort to operators who have traditionally been wary of ‘desktop’ solutions. The more closely aligned computer generated results are with practical experience, the more likely operators will embrace this technology. Whilst desktop investigations and assessments are quite often cynically reviewed, their employment offers considerable savings to both operators and government when compared to the costs and inconvenience of on-road instrumented testing.

One of the most significant findings of the principal project has been the emergence of a possible new and significant parameter for assessing and describing the behaviour of long multi-combination vehicles. This parameter is known as ***Lateral Acceleration Gain*** (LAG) and was initially identified as a possible measure of vehicle behaviour from the computer simulation data generated in Stage 1. (Refer to Appendix A for a simplified explanation of the LAG parameter).

The Stage 2 road trials verified LAG as a very good performance indicator of long vehicle handling so far as the vehicles tested in these trials were concerned. (LAG has the advantage of describing vehicle handling across a wide range of driver inputs rather than the single frequency approach offered by the standard rearward amplification measure.)

Further testing will be necessary to confirm the robustness of LAG across a wider range of vehicles and multi-combination types. However at this early stage, LAG appears to form the basis of a sound and worthwhile method for determining the driveability of multi-combinations when used in conjunction with driver steering input data.

The findings have been forwarded to the National Transport Commission's PBS project team for information and review as necessary in relation to vehicle performance measures for certain types of multi-combination vehicles.

Overarching Project
Stability and on-road performance of multi-combination vehicles with air suspension systems project

2 General Background -

2.1 Remote Areas Group (RAG)

The Remote Areas Ministerial Council (RAMC) (comprising Transport Ministers from New South Wales, the Northern Territory, Queensland, South Australia and Western Australia) was formed in 1999 to give remote area issues a high profile in the development of road transport reform, with particular reference to the national reform agenda. RAMC's principal role was to provide a high level of co-ordinated leadership in this area.

In order for the RAMC to function effectively it required an advisory body with a project, research and implementation role to support it. RAMC members agreed that this role should be performed by a body to be known as the Remote Areas Group (RAG). RAG was composed of representatives from the road transport industry and regulators from NSW, NT, Qld, SA and WA. In addition RAG had representatives from the NRTC and other national industry bodies.

The RAG was based on the Remote Areas Project Group (RAPG) which operated under the auspices of the NRTC and held its final meeting in Alice Springs on the 27th June, 1999. Essentially RAG was required to continue to progress the unfinished work of RAPG and expand its role in accordance with its terms of reference. The expanded role allowed RAG members to raise issues that were not strictly within the NRTC charter such as education programs or programs to encourage young people to consider a career in the trucking industry.

The essential role of RAG therefore, was to act as the peak advisory body to RAMC, and in addition provide advice to organizations such as the NRTC and individual jurisdictions on issues and reforms affecting remote areas. In its broader role, RAG was also permitted to resolve and implement a wide range of solutions where there was a consensus amongst its members and general agreement from RAMC.

2.2 Historical Background to the Principal Project

An increasing focus on the use of air suspension systems on heavy combination vehicles has occurred due to the implementation of higher mass limits under the national mass limits review conducted by the NRTC during 1993-1996 (1). While this is a desirable outcome for productivity reasons, further work to provide guidance to operators and manufacturers in the best use and application of air suspension systems for various multi-combination vehicle configurations was considered necessary.

As a result of the outcomes of the mass limits review, air suspension systems have become an important consideration for heavy vehicle operators seeking increased mass concessions because in most States and Territories, regulators now only allow vehicles to operate at increased mass limits if their vehicles are fitted with 'road friendly' suspension systems.

An air suspension system is considered to be suitable for higher mass applications if it has been tested and certified as a 'road friendly' suspension. A road friendly suspension is considered to be less damaging to the road and therefore is allowed to carry a greater mass. Currently the only suspensions available for heavy trailers that qualify as 'road friendly' are air suspended systems.

The industry's take-up of air suspension systems for high mass operations has been rapid and, in most cases, quite successful. Anecdotal evidence from industry, however, suggested that the use of air suspension systems in certain long combinations did not result in the best performing vehicles.

This issue was raised at the 3rd Heavy Vehicle Remote Areas Conference in Alice Springs in August 1999 and was included as an item needing further examination in the Conference Resolutions.

At the same conference the then WA Minister for Transport, announced that he intended to introduce a ministerial forum to provide a focus for important remote area issues that faced remote area operators. A group comprising senior representatives from the road transport industry, state and territory agencies and the NRTC would support the ministerial forum.

Subsequently RAMC was formed together with its support group, the RAG. RAG was chaired for its first two-year term by, Mr Howard Croxon as independent Chairman, and supported by a DOT (WA) Secretariat.

One of the major agenda items for the inaugural meeting of RAG was to examine and consider the motions moved at the Remote Ares Conference together with any other issues raised at the conference. This provided one of the WA representatives with the opportunity to formally raise the air suspension issue. The meeting agreed there was a need to examine the issue further and an action item to that effect was minuted.

Following the meeting, the Northern Territory Department of Transport & Works representative came to the conclusion that the issue could be dealt with more quickly and efficiently if a consultant was employed to undertake an industry survey with the view of obtaining a better understanding of the problems raised by operators. With the out-of-session approval of RAG members he accepted the lead agency role for the project as it stood at that time. Estill was commissioned to undertake the survey.

[1] The higher mass limits agreed in principle by Ministers in April 1998 required road-friendly suspensions certified to Vehicle Standards Bulletin (VSB) 11

A number of remote area operators were interviewed between May and June 2000 and the findings consolidated in a report entitled *Operational Stability and Performance of Air Suspensions on various Vehicle Configurations – September 2000*.

The primary areas of concern identified by Estill related to long multi-combination vehicles with air suspension systems that typically operated at high mass limits with high centre of gravity loads. There was also strong anecdotal evidence that air suspension modifications on some vehicles were being undertaken to counteract some of the reported undesirable behaviours.

Reported undesirable behaviours included increased roll, sway and lurch of the vehicle making it difficult for the driver to control the combination. Drivers also reported that air sprung prime movers had a tendency to follow road indentations requiring a greater steering effort to keep the vehicle on its intended path. Air suspended dollies were reported to increase roll, reduce stability and behave erratically under heavy braking.

Drivers also reported a loss of 'driver feel' resulting from sitting in an air suspended seat, in an air suspended cab mounted on an air suspended vehicle.

As a result, drivers reported a preference for spring dollies that they felt were safer and considered their use resulted in a combination that was much easier to control.

The survey conducted by Estill, provided sufficient anecdotal evidence to make it apparent that guidelines for the use of air suspension systems in multi combination vehicles would be a positive safety initiative and of assistance to both manufacturers and operators alike.

The results were formally presented to RAG members at the Perth meeting of RAG held on the 27th October 2000. Following much discussion the following resolutions were reached:

- *The RAG agrees that the Estill Report could now be circulated amongst interested parties.*
- *That RAG noted the report has identified possible safety issues with air suspensions in remote areas and agrees that further work is desirable to explore safety implications of air suspension in some combinations.*
- *Whilst available data does not suggest that air suspension vehicles are disproportionately represented in heavy vehicle crashes. RAG proposes to address expressed concerns, whilst not impacting on the continued extension of mass limits nationally.*
- *The RAG secretariat to develop, in consultation with the NRTC and other interested parties, Terms of Reference, Scoping, Timelines and costs to undertake further work on this issue.*

At the Dubbo meeting of RAG on the 19th February 2001, concern was expressed that the project seemed to have come to a standstill and that further urgent action was required to give the project some impetus. Consequently the terms of reference 'Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems' were agreed to at that meeting.

The terms of reference provided for three stages of investigation. The three stages of investigation are collectively referred to as the *Principal Project* whilst the sub projects are referred to according to their respective stage numbers.

Roaduser was subsequently commissioned to carry out Stage 1 of the principal project by performing computer simulations of a number of specified multi-combinations. It subsequently produced a report confirming the anecdotal evidence.

The DOT (WA) managed and financed this report in conjunction with the NRTC. Some financial assistance was also received from industry groups within RAG.

As part of the project, Roaduser has made considerable refinement of its modelling simulation to reproduce more closely the behaviour of air suspensions. This resulted in the determination that the air suspensions were not as stiff as previously thought.

The refined model has also revealed that air suspended multi combinations are very sensitive to steering inputs from the driver. This finding aligns closely with driver's anecdotal evidence of how these vehicles behave. This issue is dealt with in detail in Sections 5 and 6 of this report.

There was some strong feeling amongst certain RAG members, that was strongly supported by the project manager, that the theoretical computer simulations should be confirmed by physical instrumented testing of multi-combinations. To this end, the Livestock Transporters Association of WA, Main Roads (WA) and DPI (WA) agreed to finance the second stage of the Project.

The NRTC agreed to assist DPI (WA) in the administration of the contract and also agreed to provide additional funding. Subsequently a second contract was awarded to Roaduser to carry out the necessary on-road instrumented testing.

The trials were conducted on the Great Eastern Highway Bypass near Perth, WA between 9th and 13th of April 2004 using electronic, high technology vehicle motion data collection instruments. A closed section of the Bypass was used to carry out stylised manoeuvres, such as 'swerving', to generate large movements at the rear trailer for measurement purposes. The highways adjacent to the Bypass were used under pilot escort to obtain test measurements for normal travel over longer distances.

The outcomes derived from the data collected together with Roaduser's analysis of this data are contained in the report entitled *Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems -Stage 2 Project – January 2005*.

Operational Stability and Performance of Air Suspensions on various Vehicle Configurations – Estill and Associates Pty Ltd (September 2000)

3 Summary of the Estill Report

This report was undertaken by Estill at the request of the Northern Territory Government, Department of Transport and Works as part of a project initiated by the RAG to examine the influence of various suspension types on long, heavy road vehicle combinations. The project resulted from comments expressed by heavy multi-combination vehicle drivers in regard to unusual vehicle behaviour being experienced in certain combinations using airbag suspensions on prime movers and trailers.

The report found evidence of safety concerns with vehicles using airbag suspension, but these were largely confined to remote areas. Assessment of a limited number of accident records from one State did not indicate that vehicles using airbag suspension were over represented in accident statistics or had a higher accident rate than other vehicles. As such, they did not appear to represent an immediate major safety risk. However, Agencies agreed that further action should be taken to address the concerns identified in this review and provide remedial action.

Estill interviewed key personnel, operators, drivers and maintenance providers within the transport industry to gather the necessary data on the operational stability and on-road performance of various vehicle configurations fitted with air suspensions.

The preliminary list of companies interviewed was prepared by a sub-committee convened by the RAG. The companies selected spanned a wide range of transport operations located in the Northern Territory, Queensland, South Australia and Western Australia. The sample interviewed included operators involved in transporting livestock, frozen foods, fuel, bulk cement and bulk commodities. Estill was not restricted to the initial sample group and was able to interview additional companies/personnel as the opportunity arose during the field survey. This proved to be a worthwhile decision as it added to the randomness of the sample and provided the consultant with sufficient flexibility to gather a wider range of useful data.

Thirty-five transport operators provided “industry feedback” on the operational issues associated with the introduction of air suspension, especially in remote areas via a survey questionnaire. The survey was undertaken during face to face interviews with owners, managers, drivers and maintenance personnel. Where it was not possible to meet with these representatives in person, telephone interviews were conducted. To ensure consistency of interview, all interviewees were taken through the same questionnaire with company specific comments being recorded individually.

Respondents were asked to annotate their answers to questions for which they had no experience with “no experience”.

Eighty six percent of respondents who specified their length of experience in the transport industry had between 15–30 years experience driving spring suspended vehicles and between 5-10 years experience driving air suspended vehicles. In all cases, experience with single units and multi-combination configurations was also evident.

Discussions confirmed that spring suspension was generally preferred by respondents as it provided better stability, performance and steering and less movement in the trailers.

In single unit operation air suspension trailers were reported as behaving adequately however in multi-combination configurations the movement of any part of the vehicle seemed to negatively influence the rest of the combination. Air suspended combinations were reported to have more rear movement than spring combinations.

Air suspension was also found to have a number of operational issues including stability problems because of increased roll, sway and lurch of the vehicle, making it difficult for the driver to control the combination in a straight line.

Where air suspended prime movers were preferred, the majority indicated the main reason for fitting air was to gain increased mass and decreased commodity damage. Also all respondents identified increased driver comfort, less body stress and noise reduction as benefits of air suspension. Furthermore respondents stated that they preferred an air suspended prime mover combination with spring suspended trailers and dollies to lessen any sway or roll with the trailers.

The suspension of the prime mover was identified as critical in the overall stability of the vehicle combination. Spring suspension on both the dolly and trailer was found to positively effect the stability of the overall vehicle combination while air suspension was identified as negatively impacting on stability.

Drivers experience suggested that prime movers fitted with air suspension followed every little indentation in the road and had a tendency to 'wallow' from side to side thus requiring countermeasures to keep the vehicle on course. These 'counter measures' were reported to result in adverse effects that often caused the configuration to lose stability and roll (in some cases) or 'lurch' to a new position on the road.

Drivers of high centre of gravity loads (eg. livestock/freezer) also reported greater lean and roll with air suspended prime movers. The stability of high centre of gravity vehicles was thought to be effected by the roll that is set up from the levelling of the air bags, which in turn, effected the total performance of the overall combination. These operators also reported significant vehicle stability and control problems with long combinations equipped with air suspended trailers and dollies.

In relation to cornering, the majority of drivers agreed that prime movers (fitted with air) lean considerably more when negotiating a corner and hence caused the driver to correct, which effects the second and third trailer with roll and sway. Discussions with all operators revealed that tandem air suspended dollies moved more than spring suspended dollies and under braking behaved more erratically. As a result, most operators identified a preference for spring dollies as they were found to be more controllable.

In relation to on road performance, drivers commented that combinations were more difficult to control if an air suspended prime mover was used. As a result, drivers in air suspended prime movers reported that they drove with more caution, particularly when entering corners and rough undulating patches.

Nearly all drivers commented that air suspension was “load friendly not road friendly” and that drivers were more confident when driving on spring suspension as it provided a “better feel” as to how the vehicle was performing.

Super single tyres installed on the front steering axle of air suspended prime movers was reported to give a wider tyre footprint and hence improved handling and stability. Super singles were also reported to promote greater recovery when returning from the unsealed hard shoulder to the sealed pavement.

The majority of respondents stated that air suspension required more maintenance than spring suspension. Twenty seven companies out of a possible thirty five stated that vehicles were more expensive to maintain with air suspension.

The Estill report concluded with the following recommendations:

1. *Additional field research be undertaken in relation to the performance and stability of air suspensions when used in multi-combination configuration in relation to:*
    - *Configurations with 2 or more trailers;*
    - *Operation on rough sealed and unsealed roads;*
    - *Stability on narrow pavements tracking on and off the sealed section;*
    - *Effect on Stability using low profile and Super Single tyres fitted to steer axles;*
    - *Stability on close curved road alignment;*
    - *Determining centre of gravity(C of G) height limits;*
    - *Trailer movement/on road characteristics for configurations incorporating air prime movers versus spring prime movers; and*
    - *Effect of Speed and C of G on configurations with air suspensions versus configurations with steel suspensions.*
2. *Investigate and evaluate “After market improvements” to air suspensions.*
3. *Encourage manufacturers to work with the transport industry in developing best design practice ie location of shock absorbers, ride height valves etc to improve performance of air suspensions applicable to multi-combination configurations.*
4. *Improve accident collection techniques to include suspension types in accident questionnaire to develop a history file on accident patterns.*

Principal Project

Stability and on-road performance of multi-combination vehicles with air suspension systems project

4 Background Summary – Principal Project (Scientific Investigation)

4.1 Background to the Principal Project

Following the release of the Estill report in September 2000, RAG agreed to continue the investigation at a more scientific/engineering level. The project pursued by RAG was based on the terms of reference *Stability and On-Road Performance of Multi-Combination Vehicles With Air Suspension Systems* agreed to at the Dubbo meeting of the 19th February 2001. (Refer Appendix B).

The TOR provided for three stages of investigation. The three stages of investigation are collectively referred to as the *Principal Project* whilst the sub projects are referred to according to their respective stage numbers.

Roaduser was subsequently commissioned to carry out Stage 1 of the principal project by performing computer simulations of a number of specified multi-combinations. It subsequently produced a report entitled *Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems – Stage 1 Project – June 2002* that summarised the findings of the simulations.

The then DOT (WA) managed and financed this report in conjunction with the NRTC. Some financial assistance was also received from industry groups within RAG. The completion of this report concluded Stage 1 of the Principal Project.

Two important issues emerged from these results. Firstly, the computer simulations validated much of the anecdotal evidence gathered by Estill in terms of vehicle handling – for example, the simulations supported the driver's assertion that air suspended long combinations were difficult to drive, but easier to drive if steel suspended dollies were used in place of air. Secondly, these handling difficulties could be attributed to the sensitivity of the combination to the drivers steering frequency.

There was some strong feeling amongst certain RAG members, that was strongly supported by the project manager, that the theoretical computer simulations should be validated by physical testing of instrumented multi-combinations. To this end, the Livestock Transporters Association of WA, Main Roads (WA) and DPI (WA) agreed to finance the second stage of the Project.

The NRTC agreed to assist DPI (WA) in the administration of the contract and also agreed to provide additional funding. Subsequently a second contract was awarded to Roaduser to carry out the necessary on-road instrumented testing.

The trials were conducted on the Great Eastern Highway Bypass near Perth, WA between 9th and 13th of April 2004 using electronic, high technology vehicle motion data collection instruments. A closed section of the Bypass was used to carry out stylised manoeuvres, such as ‘swerving’, to generate large movements at the rear trailer for measurement purposes. The highways adjacent to the Bypass were used under pilot escort to obtain test measurements for normal travel over longer distances.

Special mention needs to be given to Main Roads (WA) for assisting financially in the execution of Stage 2 of the principal project and also for their assistance in organizing the road closures and traffic management and for allowing access to these facilities at no cost. Also special mention needs to be given to the members of the Livestock Transporters Association of WA who unselfishly offered their vehicles, drivers and personal time at no cost to the project.

The outcomes derived from the data collected together with Roaduser’s analysis of this data are contained in the report entitled *Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems - Stage 2 Project – January 2005.*

Summary of the 'Stability and on-road performance of multi-combination vehicles with air suspension systems Stage 1 Project' report – June 2002

By Robert Di Cristoforo, Roaduser Systems Pty Ltd

5 Summary of Principal Project - Stage 1 Report

5.1 Stage 1 – Determination of key influencing factors

The purpose of Stage 1 was to determine the characteristics of heavy vehicle suspensions that have the most influence on the dynamic behaviour of high mass, high centre-of-gravity, long combination vehicles. The work was based on Roaduser's vehicle dynamics simulation methods, which have been developed over more than ten years of Roaduser's investigations into the dynamics of heavy vehicles.

Computer simulation was considered to be the most cost-effective method of carrying out Stage 1, because many different scenarios could be investigated quickly and safely. It was also possible to use computer simulation to investigate scenarios that are difficult or impossible to achieve with currently available equipment or technology. As a means of comparison between different scenarios, computer simulation could be used to provide insight into the sensitivity of vehicle dynamic behaviour to certain changes in vehicle design.

The computer simulation process identified a number of dynamic performance issues present in some of the high mass, high centre-of-gravity, long combination vehicles investigated.

5.2 Vehicle dynamics

The motions of a combination vehicle are a complex mix of many simple motions (or 'modes') such as body bounce and body roll. Each of these modes has a different frequency, or rate of oscillation, so that when many modes occur at the same time, the overall motion of the vehicle is complex and difficult to analyse.

Advanced mathematics can be used to split complex vehicle motion into its constituent 'modes'. Engineers use these mathematical methods to gain a better understanding of the complete dynamic system.

The two principal dynamic modes of a long combination vehicle are:

- the *yaw mode* – the side-to-side swaying (or pendulum action) of the trailers; and
- the *roll mode* – the side-to-side rolling (or leaning) of the trailers.

As a result, heavy vehicle dynamic behaviour is often considered to be a *yaw-roll* phenomenon.

Stage 1 of the project found that some high mass, high centre-of-gravity, long combination vehicles tend to exhibit seemingly unstable motions that are a combination of the yaw and roll modes. These motions were found to have:

- low 'frequency' – more than 2.5 seconds per cycle (0.4 Hz);
- low 'damping' – oscillations take a long time to die away; and
- high 'gain' – small disturbances at the prime mover result in large disturbances at the rear.

Although they can appear to be unstable, these motions are simply nearer to the point of instability than the motions of other, more stable, long combination vehicles. These characteristics can make a combination vehicle difficult for a driver to control and unpredictable to other road users.

5.3 Driver-vehicle interaction

The behaviour of the rear trailer of a combination is greatly affected by the way in which the prime mover is steered. Not only is the amount of steering important, but also the frequency, or rate, of steering reversals.

Figure 1 shows how the sensitivity of a combination vehicle varies with steering frequency. There is often a small range of steering frequencies in which comparatively large motions are induced at the rear trailer; this range of steering frequencies is indicated by the peak of the graph, being the 'resonant' or 'natural' frequency of the yaw-roll mode. For most combination vehicles, this peak occurs at a frequency of around 0.4 Hz (2.5 seconds per cycle).

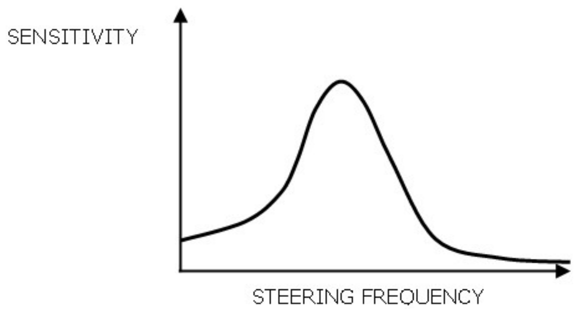

Figure 1: Resonant frequency of a combination vehicle

The size of the peak indicates the sensitivity (or gain) of the combination at its resonant frequency; a smaller peak indicates a better performing vehicle that is easier to predict and control across the range of steering frequencies.

5.4 Stage 1 findings

Stage 1 of the project found that higher mass and centre-of-gravity height tends to increase the size of the peak and reduce its resonant frequency. Air suspension was also found to reduce the resonant frequency. Variations in resonant frequency can have an effect on the driver-vehicle interaction if the vehicle's resonant frequency approaches the driver's dominant steering frequency.

Other issues identified in Stage 1 are related to the following measures:

- yaw damping – the rate at which swaying motions of the rear trailer diminish after a steering disturbance at the prime mover;
- trailing fidelity – the ability of the combination to track in a straight line when travelling along crowned, undulating roads; and
- prime mover handling – the understeer/oversteer behaviour of the prime mover at various levels of turning severity.

It was found that the use of air suspensions on high mass, high centre-of-gravity, long combination vehicles can adversely affect each of these performance measures. Yaw damping can be significantly reduced, meaning that the combination will tend to sway continuously as it travels along the road. Trailing fidelity can degrade such that the combination tracks poorly and requires additional road width to accommodate its increased swaying motions. Prime mover handling can degrade such that the vehicle enters into oversteer conditions during relatively low severity turns and becomes difficult for the driver to control.

The characteristics of suspension design that were found to be most influential in the behaviour of long combination vehicles are:

- *roll stiffness* – the resistance provided by the suspension to limit rolling (or leaning) of the trailers during travel. Roll stiffness is highly variable between different types of suspension;
- *roll centre height* – the height of the imaginary axis about which the trailer pivots on the suspension during rolling motion. This is usually slightly above the axle centreline and can be controlled to some extent by suspension design; and
- *roll steer coefficient* – the ratio of axle steer to body roll when the body leans over. When a body rolls on its suspension, there is usually a small amount of axle steer induced. This steer is usually towards the direction of lean, and can be controlled fairly readily through suspension design.

Most commercially available suspension systems have similar characteristics for roll centre height and roll steer coefficient. These characteristics are controlled by the geometric design of the suspension and can be affected by the selection of bushings and other design details.

Roll stiffness, however, is highly variable across the range of commercially available suspension systems. Roll stiffness was found to be the most influential characteristic in the dynamic behaviour of high mass, high centre-of-gravity, long combination vehicles.

These results showed that there is potentially a problem with the application of air suspension systems for some types of vehicle combinations. Although the findings of the computer study were quite clear, it was recommended that field trials be conducted to confirm the findings and to validate the simulation modelling methods used in Stage 1.

The conducting of field trials under Stage 2 of the project was welcomed by industry. For some years the use of computer simulation methods for assessing vehicle dynamics has been a controversial issue within the industry, and it was considered that testing needed to be carried out to confirm the accuracy of the simulation models used in Stage 1.

Summary of the ‘Stability and on-road performance of multi-combination vehicles with air suspension systems Stage 2 Project’ report – January 2005

By Robert Di Cristoforo, Roaduser Systems Pty Ltd

6 Summary Principal Project - Stage 2 Report

6.1 Test program

The purpose of Stage 2 was to conduct field trials on a number of vehicles using high technology vehicle motion data collection to confirm the findings of Stage 1 and to provide a high level of confidence in the predictions of Roaduser’s computer simulation models.

The trials were conducted on the Great Eastern Highway Bypass near Perth, WA between April 9 – 13, 2004. A closed section of the Bypass was used to carry out stylised manoeuvres, such as ‘swerving’, to generate large movements at the rear trailer for measurement purposes. The highways adjacent to the Bypass were used under pilot escort to obtain test measurements for normal travel over longer distances.

The Stage 1 project recommended that the trials should investigate the behaviour of fully loaded triple-trailer livestock vehicles with both air and mechanical suspension systems. Three vehicles were selected, namely:

- ‘All Air’ – air-suspended trailers and dollies;
- ‘Air/Mech’ – air-suspended trailers with mechanically-suspended dollies; and
- ‘All Mech’ – mechanically-suspended trailers and dollies.

Photographs of the test vehicles are shown in Figure 2.

Figure 2: Test vehicles – 'All Air', 'Air/Mech' and 'All Mech'

The same cattle were loaded onto the vehicles for each test. All three vehicles were tested at axle loads slightly higher than the general gross mass limit of 115.0 tonnes. The actual test loads were:

- 'All Air' – 118.4 tonnes;
- 'Air/Mech' – 117.9 tonnes; and
- 'All Mech' – 115.9 tonnes.

The vehicles were fitted with sophisticated motion detection instrumentation to provide details of speed, trailer yaw, trailer roll, trailer lateral acceleration (side forces), driver steering and suspension movement.

6.2 Key test results

The field trials yielded some remarkable findings regarding the interactions between driver and vehicle. These findings are associated with:

- how much effort is required for the driver to control the vehicle; and
- how the vehicle's frequency response relates to the driver's dominant steering frequency.

Driver steering effort was evaluated by determining the 'average' amount of side-to-side steering using a statistical technique known as the 'Root-Mean-Square (RMS) method'. RMS steering angles were compared between combinations to rank the steering effort required to control each combination. It was found that the combinations containing mechanical suspensions ('Air/Mech' and 'All Mech') demonstrated RMS steering angles of around 80% of that demonstrated by the 'All Air' configuration, which implies that the drivers of the mechanically-suspended combinations were required to do 20% less work than the driver of the air-suspended combination.

Further analysis of driver steering behaviour showed that, as well as differences in RMS steering angle being observed, there were significant differences in dominant steering frequency. A lower dominant steering frequency is another indicator of reduced driver effort to control a combination. Figure 3 shows the results of a frequency analysis of driver steering behaviour for each vehicle, where it can be seen that the driver of the 'All Mech' combination is steering with the lowest dominant frequency.

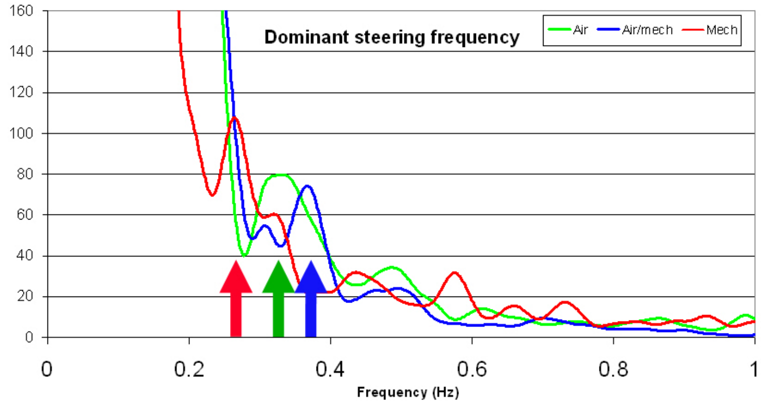

Figure 3: Frequency analysis of driver steering behaviour

Given that combination vehicles were found to have remarkably different dynamic responses to steering inputs of different frequencies, the frequency response of each of the three test vehicles was evaluated. This was measured in terms of 'gain' or 'ratio' between the lateral acceleration measured at the towing vehicle versus that measured at the rearmost trailer. This ratio is referred to as the 'Lateral Acceleration Gain (LAG) and is explained in more detail in Appendix A.

Figure 4 shows these frequency response results, where it can be seen that the 'All Air' and 'Air Mech' combinations each demonstrate a high peak in gain just below 0.4 Hz, while the 'All Mech' combination demonstrates a much lower 'split peak' at around 0.5 to 0.6 Hz. The horizontal locations of these peaks are the steering frequencies at which the most noticeable dynamic vehicle movements will be induced in each vehicle.

The split peak in the 'All Mech' combination shown in Figure 4 is believed to be derived from the frequency-separation of the yaw and roll modes due to the marked increase in trailer roll stiffness for that vehicle. The yaw peak and the roll peak are identified in Figure 4 on the red curve over the red arrows. The other two vehicle combinations therefore have higher peaks that are effectively a summation of both the yaw and roll modes. When the yaw and roll modes have a similar natural frequency, there is potential for the characteristic low frequency, low damping 'yaw-roll' mode to be prominent in the vehicle's movement during travel.

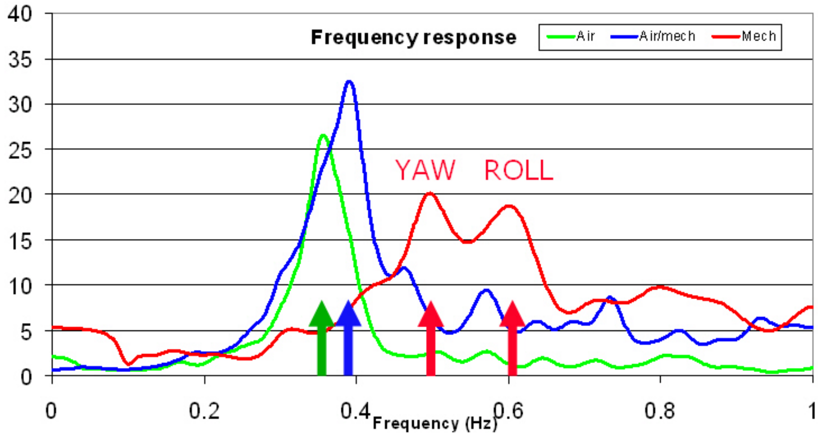

Figure 4: Frequency analysis of vehicle response

Combining the results of Figure 3 and Figure 4, the interaction between the driver and the combination vehicle can be assessed. Figure 5 shows the comparison of driver and vehicle characteristics for the 'All Air' and 'Air/Mech' combinations, where it can be seen that each driver's dominant steering frequency (shown as 'Power Spectral Density (PSD) (dotted line)) is coincident with the natural frequency of the combination (shown as 'Transfer function' (solid line)). This indicates that most of the driver's steering activity is at a frequency which induces the largest movements in the combination.

In other words what this means is that for these vehicles, a small movement of the steering wheel results in a highly magnified amount of movement at the rear trailer. Drivers must therefore always be alert, as they need to 'drive' the rig continuously.

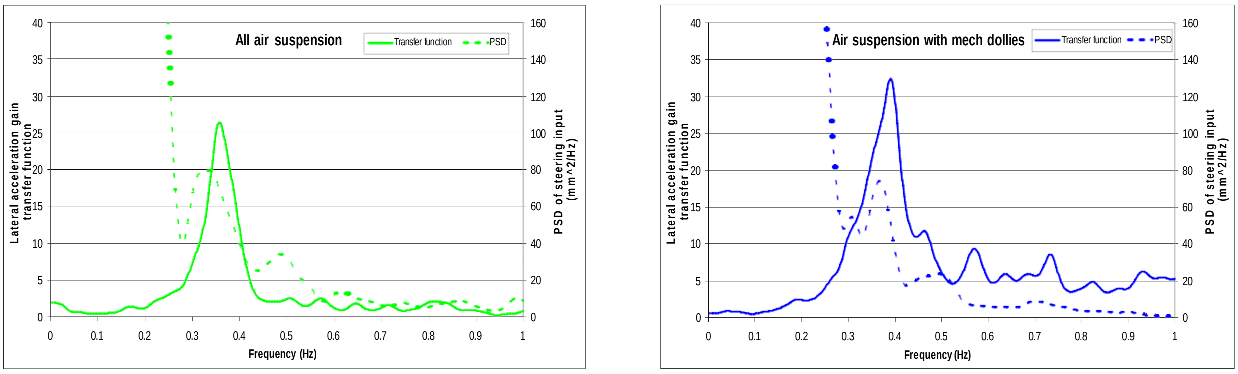

Figure 5: Driver-vehicle interaction – 'All Air' and 'Air/Mech' combinations

Figure 6 shows the comparison of driver and vehicle characteristics for the 'All Mech' combination, where it can be seen that the driver's dominant steering frequency is well away from the natural frequency of the combination. This indicates that most of the driver's steering activity is at a frequency which does not induce large movements in the combination. In this case the driver does not need to work as hard to keep the combination on a straight path.

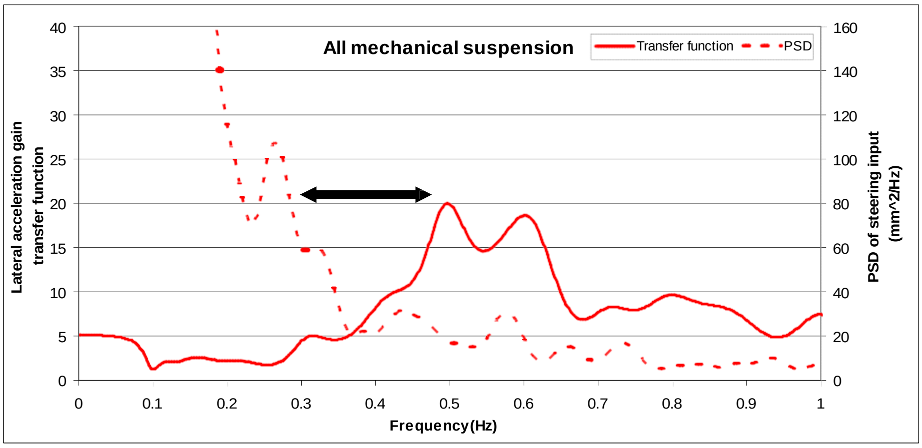

Figure 6: Driver-vehicle interaction – 'All Mech' combination

6.3 Other test results

The remarkable driver-vehicle interactions identified in the field trials had significant effects on the measured motions of the vehicles. Table 1 shows some of the Root Mean Square (RMS) vehicle movements measured during normal travel at speeds of around 80 km/h. Considering the 'All Air' vehicle to be the '100%' benchmark, relative performance can be evaluated. The 'Air/Mech' vehicle demonstrates reductions of 21% and 25% in yaw and roll motions of the rear trailer respectively, with a 44% reduction in lateral acceleration at the rear trailer. The 'All Mech' vehicle demonstrates reductions of

62% and 72% in yaw and roll motions of the rear trailer respectively, with a 47% reduction in lateral acceleration at the rear trailer.

Table 1: Relative performance of vehicle movement during normal travel

	'All Air'	'Air/Mech'	'All Mech'
Yaw of rear trailer	100%	79%	38%
Roll of rear trailer	100%	75%	28%
Lateral acceleration of rear trailer	100%	56%	53%

6.4 Performance-based standards

Using the models calibrated against the test data, the three combination vehicles were evaluated for the following Performance-Based Standards (PBS). (See NTC website for more information about PBS – **www.ntc.gov.au):**

- Tracking Ability on a Straight Path (TASP);
- Static Rollover Threshold (SRT);
- Rearward Amplification (RA);
- High-Speed Transient Offtracking (HSTO); and
- Yaw Damping Coefficient (YDC).

The performance of the vehicles evaluated against Level 4 PBS is summarised in Table 2.

Table 2: Performance of combinations evaluated against Level 4 PBS measures

PBS measure	Performance target (Level 4)	Vehicle 1 (Mech dollies)	Vehicle 2 (All air)	Vehicle 3 (All mech)
TASP	≤ 3.30 m	3.15 m 3	3.18 m 3	3.10 m 3
SRT	≥ 0.35 g	1st unit 0.36 g 3 2nd unit 0.34 g 2 3rd unit 0.34 g 2	1st unit 0.36 g 3 2nd unit 0.33 g 2 3rd unit 0.33 g 2	1st unit 0.36 g 3 2nd unit 0.34 g 2 3rd unit 0.34 g 2
RA	≤ (5.70 × SRTrrcu*)	2.662	2.482	2.742
HSTO	≤ 1.20 m	1.44 m 2	1.48 m 2	1.41 m 2
YDC	≥ 0.15	0.092	0.092	0.122

- rrcu = rearmost roll-coupled unit

Table 2 highlights the differences in performance between the three road trains. Although the differences in SRT are small, the dynamic activity (quantified by the remaining measures) varies more noticeably. Considering that the main differences between the combinations are in the suspensions, these performance variations represent significant effects due to suspension alone.

While the general trend is towards improved performance in the mechanically-suspended combination, the RA results show the opposite trend. RA has a tendency to increase for vehicles with mechanical suspensions, because the improved tracking of the rear trailer produces a more rigid lateral movement than a trailer which takes a wider, more gentle sweep in the lane change (as for an air-suspended trailer). When good HSTO performance is observed, the RA performance can, to some extent, be neglected.

6.5 Validation of computer simulation models

Roaduser's computer simulation models were validated against actual test data obtained from the field trials. The models were used to replicate actual test manoeuvres so that model output could be compared with measurements taken by sensors fitted to the vehicles.

Figure 7 shows examples of lateral acceleration measurements taken during lane change manoeuvres (identified as *Test* curves in Figure 7) on the Great Eastern Highway Bypass test site for each test vehicle. The measurements are compared with output from the computer simulation models (identified as *Sim* curves in Figure 7). It is apparent that the respective pairs of curves follow each other closely thereby indicating that there is a high level of correlation between the test results and those obtained from the simulations. This demonstrates graphically the validity of the computer simulation model.

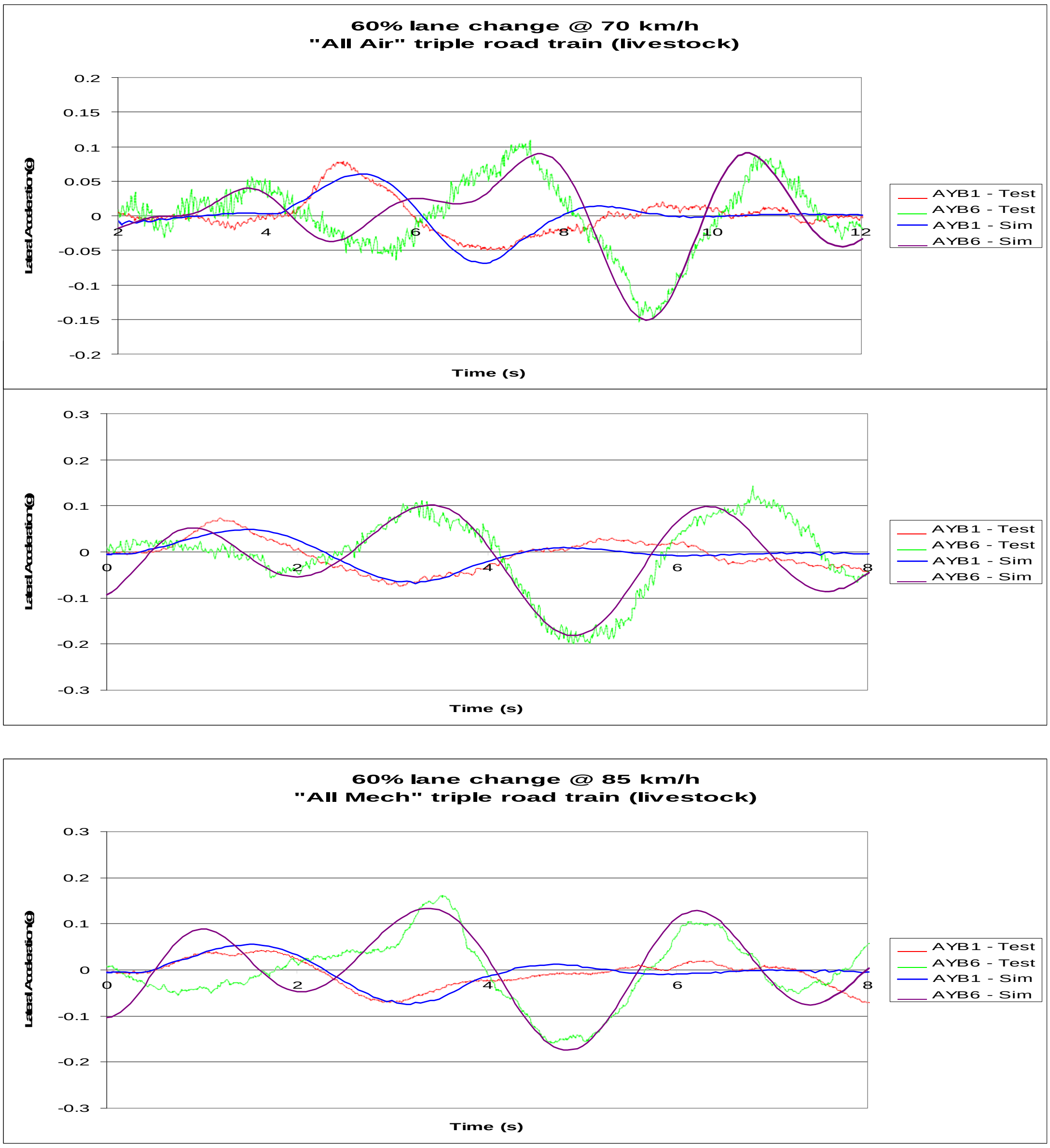

Figure 7: Validation of computer simulation models

6.6 Alternative vehicle configurations

Further to the analysis of triple road train livestock configurations presented in the main body of this report, similar testing and computer simulation has been carried out for the following innovative vehicle configurations:

- BAB-quad livestock road train with air suspension (except for mechanical dolly);
- A+A+B side tipper combination with air suspension, laden to: (i) standard national axle mass limits and (ii) concessional mass limits (as are available in WA); and
- A+B3 container combination with mechanical suspension, nominally laden to standard national axle mass limits.

(The trials on the A+A+B side tipper combination and the A+B3 container combination were sponsored by Queensland Transport).

The analysis of these additional vehicles was performed as a means of examining:

- the improvements in dynamic performance that can be achieved through the use of innovative vehicle configurations;
- the potential suitability of air suspension systems for certain innovative vehicle configurations; and
- the ability to predict the dynamic performance of innovative vehicle configurations with reasonable accuracy using computer simulation (and that accurate simulation modelling is not limited only to conventional triple bottom road trains).

Dimensioned drawings of these vehicles are illustrated in Figures 8, 9 and 10 whilst their respective photographs are shown in Figurers 11, 12 and 13 respectively.

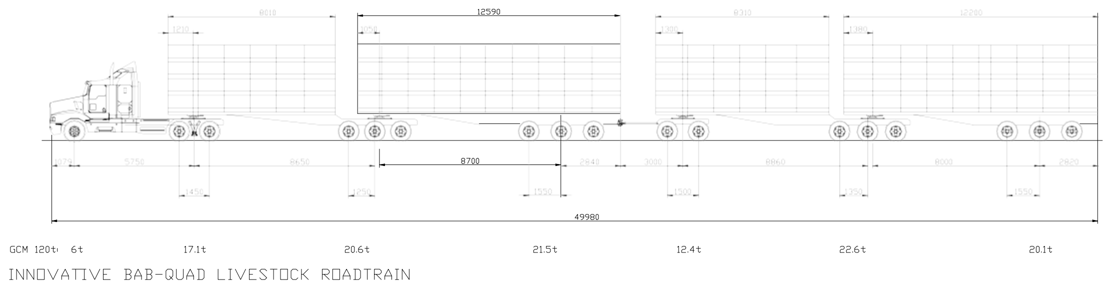

Figure 8 Innovative BAB-quad (Livestock)

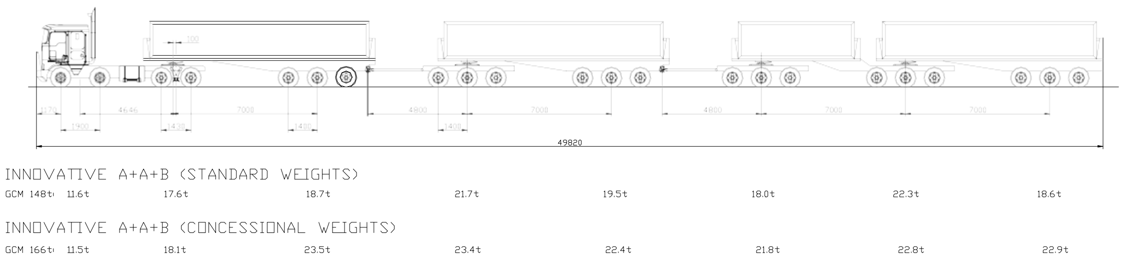

Figure 9 Innovative A+A+B (Tipper)

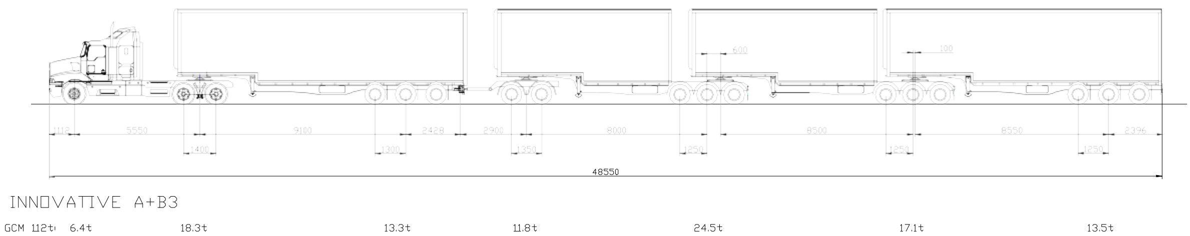

Figure 10 Innovative A+B3[2] (Container)

[2] Diagram shows trailers as curtainsiders, although one curtainsider and three skeletal trailers were supplied for testing.

Figure 11 BAB-quad livestock combination

Figure 12 A+A+B side-tipper combination

Figure 13 A+B3 container combination

Figure 14 shows the plot of steering inputs for each innovative vehicle. This is a similar plot to that shown in Figure 3 for the three livestock multi combinations. As is the case in Figure 3, the dominant frequency for each vehicle can be identified as the peak in each curve. In all cases the dominant steering frequency is around 0.25 – 0.3 Hz, which is a low level of steering activity representing a driver comfortably in control of the vehicle.

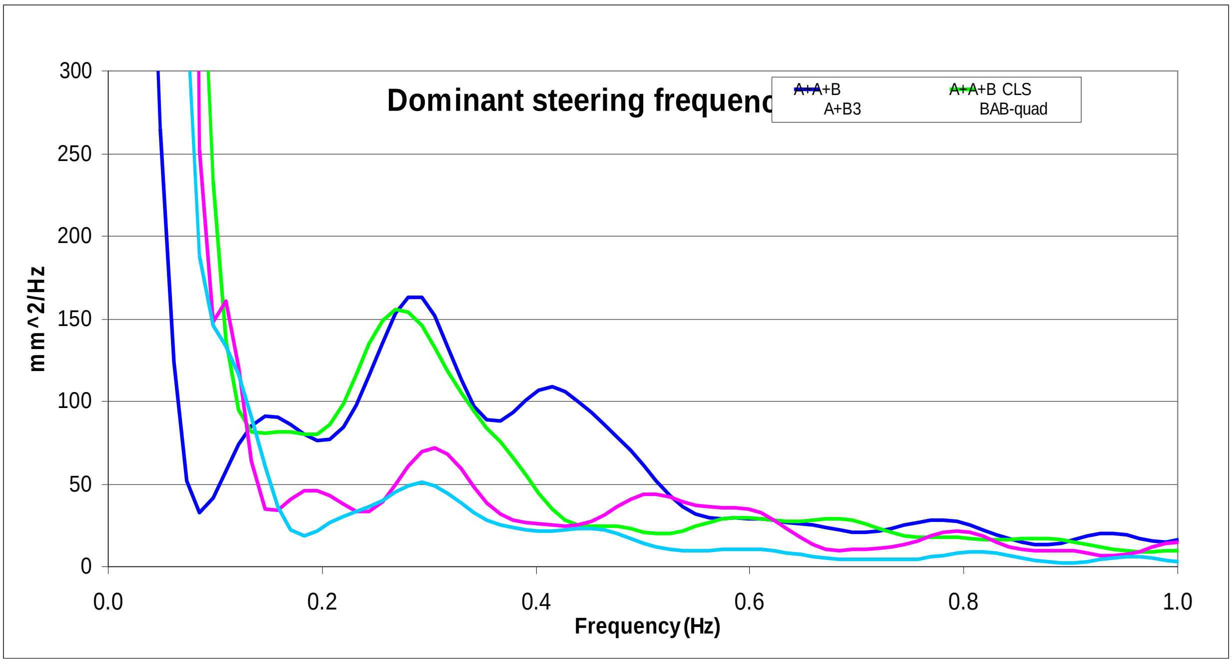

Figure 14. Frequency analysis of driver steering behaviour for the innovative vehicles

Figure 15 shows the lateral acceleration gain for each of the innovative vehicles. The A+A+B and A+B3 vehicles demonstrated peak lateral acceleration gain at around 0.55 – 0.6 Hz, while the BAB-quad demonstrated a peak at around 0.4 Hz. It can be seen that the peak lateral acceleration gain of each vehicle occurs at a frequency that is well separated from the driver's dominant steering frequency. Therefore, natural steering behaviour is not likely to induce unwanted dynamic behaviour in the combination.

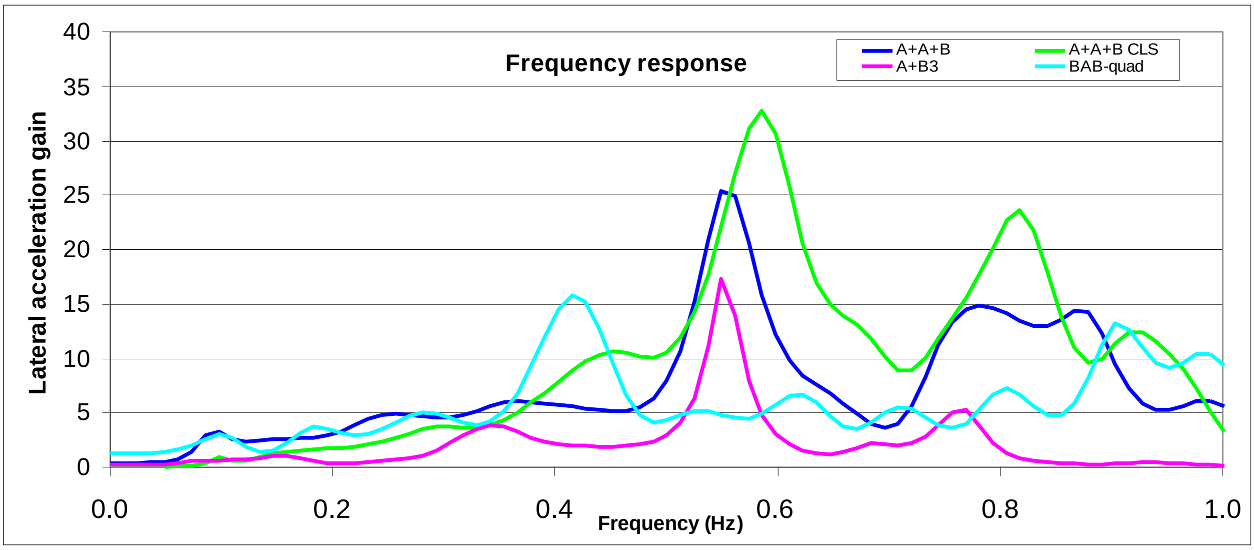

Figure 15. Lateral acceleration gain

6.7 Model validation and calibration

Before the RATED simulation models (the computer models used by Roaduser) were used to evaluate the performance of the combination vehicles, the models were validated against actual test data obtained from the Great Eastern Highway Bypass test site. Any discrepancies between the model behaviour and the test results could be removed by calibration of the models (by adjusting suspension roll stiffness, for example), so that a reliable PBS assessment could then be carried out under standard conditions.

Test conditions which often interfere with the quality of test results include:

- Road cross-fall;
- Driver steering accuracy;
- Vehicle loading; and
- Test speed.

Once the models are validated under the actual (imperfect) test conditions, they can be used to evaluate the performance of the vehicles under standard conditions (ie. flat road surface with correct driver steer input, axle loads and test speeds).

The models were used to replicate selected test manoeuvres at actual test weights, at the recorded test speeds with the measured road cross-fall applied. Driver steering error during the SAE lane change was replicated also. In all cases very good comparison was observed between the simulation models and the recorded test data, with only minor adjustments required in some cases.

6.8 Output from calibrated models

Figures 16, 17, 18 and 19 show the comparison of lateral acceleration at the prime mover and the rear trailer for each innovative test vehicle. It can be seen that good comparisons exist between the simulation and test data, with minor adjustments of the model parameters.

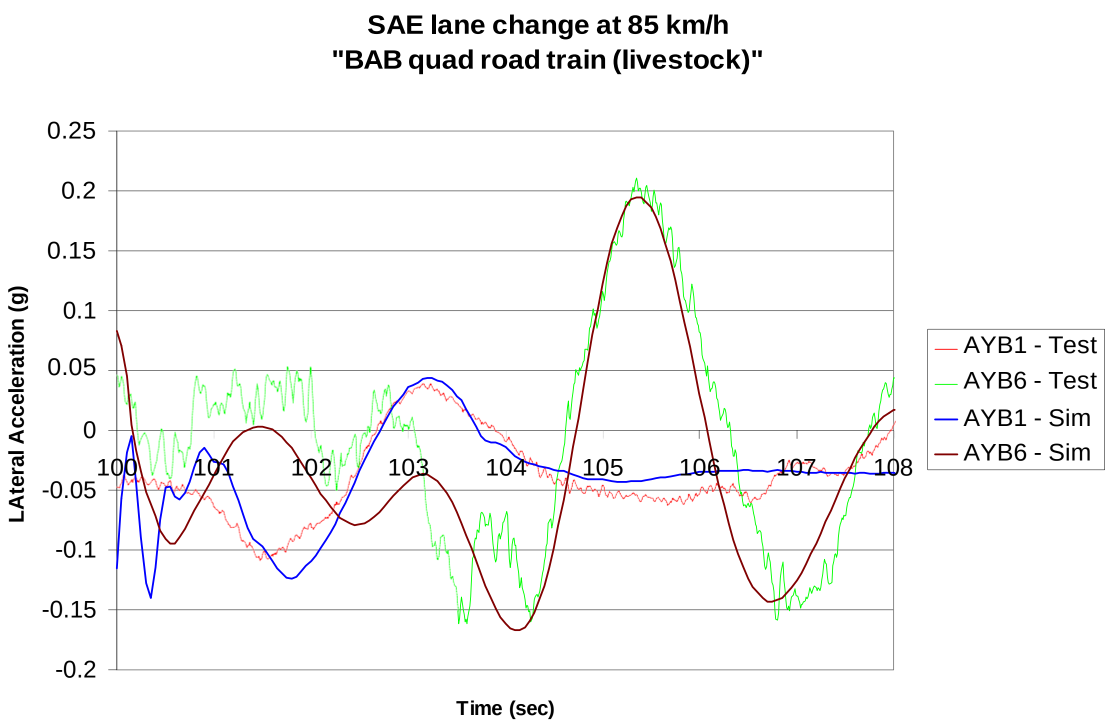

Figure 16. **Comparison of test and simulation - BAB quad road train**

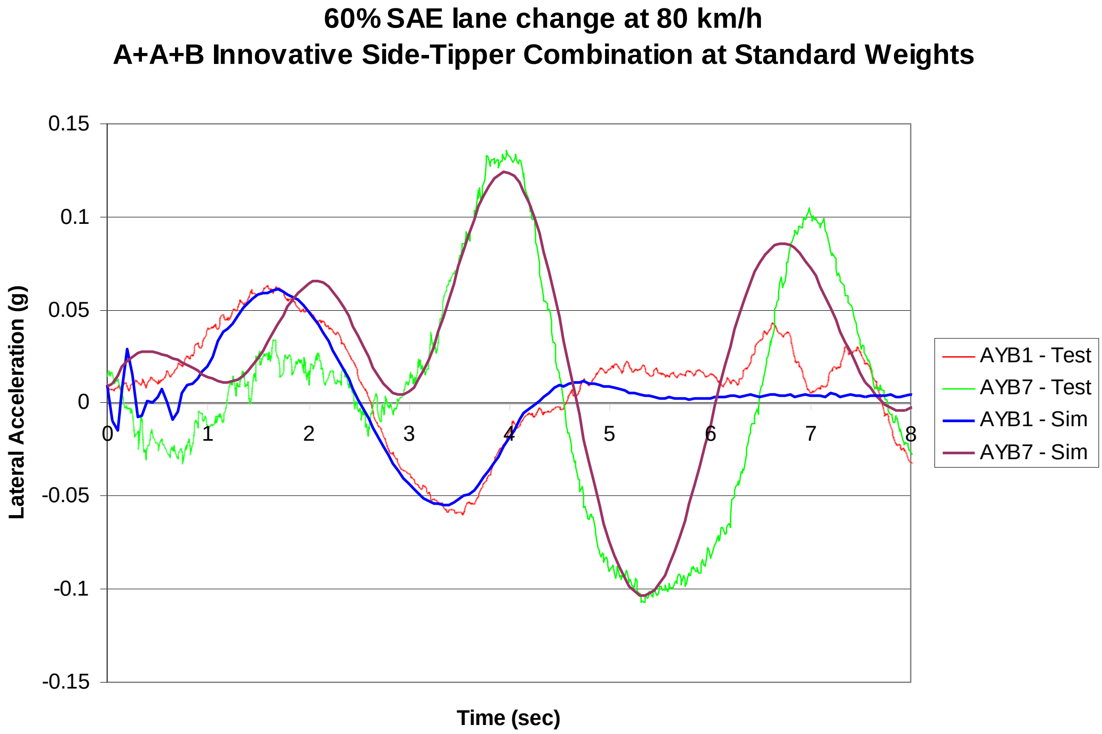

Figure 17. **Comparison of test and simulation - A+A+B Standard axle loads**

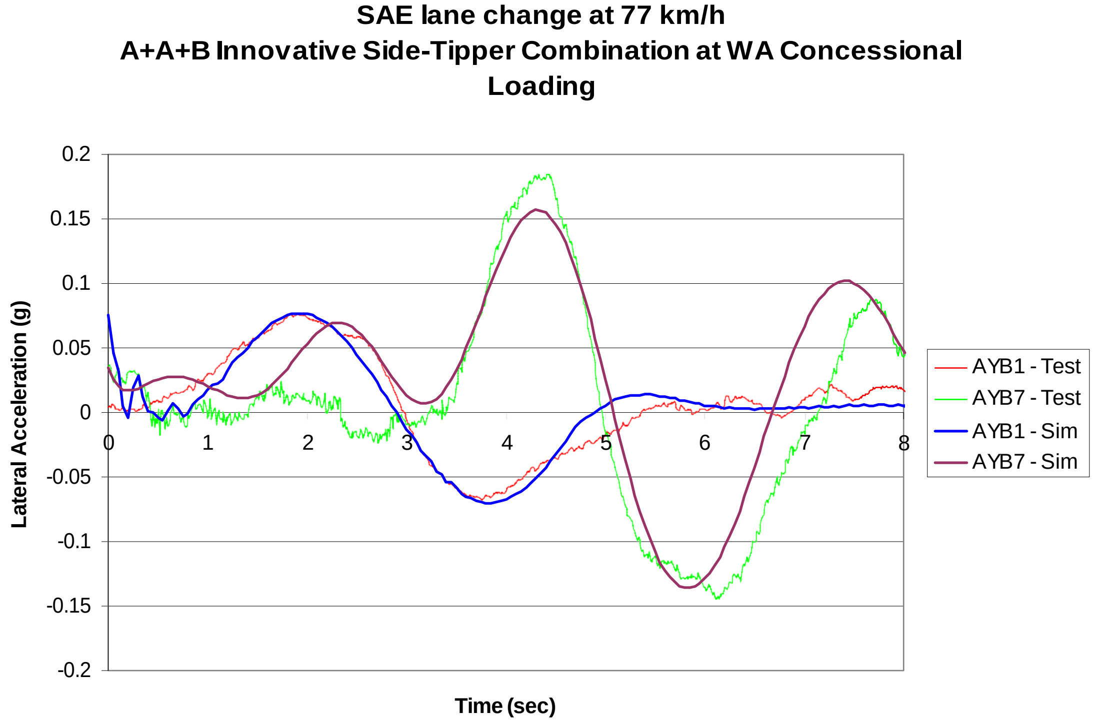

Figure 18. Comparison of test and simulation - A+A+B concessional axle loads

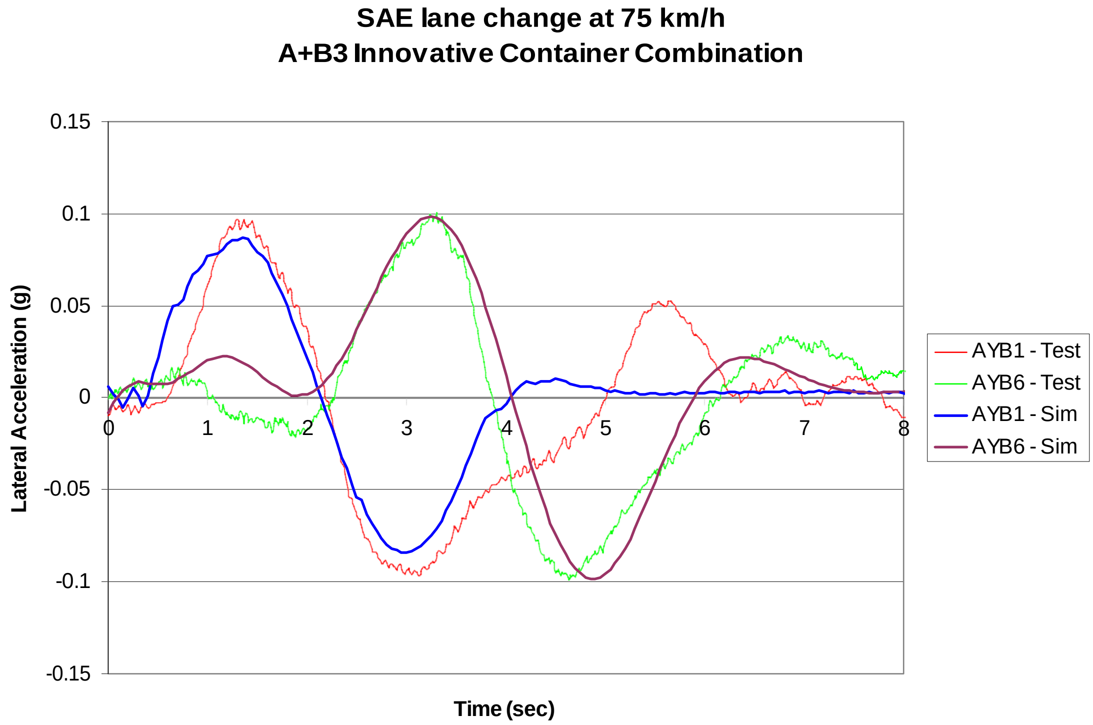

Figure 19. Comparison of test and simulation – A+B3 quad road train

6.9 Performance comparisons using simulation

Using the models calibrated against the test data, the three combination vehicles were evaluated for the following performance based standards:

- Tracking Ability on a Straight Path (TASP);
- Static Rollover Threshold (SRT);
- Rearward Amplification (RA);
- High-Speed Transient Off-tracking (HSTO); and
- Yaw Damping Coefficient (YDC).

The performance of the vehicles evaluated against Level 4 PBS is summarised in Table 3.

Table 3: Performance of innovative vehicle evaluated against Level 4 PBS measures

PBS measure	Performance target (Level 4)	BAB quad (livestock)	A+A+B (side tipper) Standard weight	A+A+B (side tipper) concessional weight	A+B3 (container)
TASP	≤ 3.30 m	2.97 m 3	2.90 m 3	2.99 m 3	2.96 m 3
SRT	≥ 0.35 g	1st unit 0.34 g 2 2nd unit 0.32 g 2	1st unit 0.54 g 3 2nd unit 0.52 g 3 3rd unit 0.51 g 3	1st unit 0.50 g 3 2nd unit 0.47 g 3 3rd unit 0.46 g 3	1st unit 0.36 g 3 2nd unit 0.35 g 3
RA	≤ (5.70 × SRTrrcu*)	1.66 3	2.47 3	2.73 2	1.05 3
HSTO	≤ 1.20 m	1.35 m x	1.35 m 2	1.94 m 2	0.80 m 3
YDC	≥ 0.15	0.31 3	0.14 2	0.08 2	0.36 3

Table 3 shows the differences in performance between the four innovative vehicles. The differences in SRT can be attributed to the different body types on each vehicle. The A+A+B combinations had tipper bodies with low COG heights, while the BAB with livestock bodies and the A+B3, with containers had considerably higher COG heights.

The A+A+B combinations were seen to exhibit the worst high speed dynamic results. The A+B3 on the other hand, had excellent high-speed dynamic performance for a combination vehicle of its size and mass. This vehicle had virtually no RA, and easily satisfied HSTO and YDC, with performance figures closer to that of a much shorter combination.

7 Conclusions and Findings

7.1 Stage 1 and 2 Findings

The evidence gathered during the Stage 2 project field trials verified the findings of the Stage 1, simulations. This in turn resulted in a greater level of confidence in the ability of computer simulation techniques to determine and predict real life performance of heavy combination vehicles.

The simulation program used in Stage 1 and Stage 2 also proved to be reliable in predicting the performance of innovative vehicles and is therefore not limited to the assessment of standard road train configurations.

The results are consistent with driver and operator experience.

A scientific explanation is now available as to why fully air suspended long and heavy combination vehicles with a high centre of gravity are more difficult to drive compared to other vehicles.

The extremely good results obtained from the innovative vehicles tested indicate that there is a great potential for the increased use of innovative vehicles in the transportation of livestock which could deliver higher productivity with increased road safety.

Lateral Acceleration Gain' The *Lateral Acceleration Gain* (LAG) parameter emerged as a possible new and significant measure for assessing and describing the operation of long multi-combination vehicles as a result of the computer simulation data gathered in Stage 1.

The Stage 2 road trials verified LAG as a very good performance indicator of long vehicle handling. LAG has the advantage of describing vehicle handling across a wide range of driver inputs rather than the single frequency approach offered by the standard rearward amplification measure.

Further testing will be necessary to confirm the robustness of LAG across a wider range of vehicles and multi-combination types. However at this early stage, LAG appears to form the basis of a sound and worthwhile method for determining multi-combination drivability when used in conjunction with driver steering input data.

The findings have been forwarded to the National Transport Commission's PBS project team for information and review as necessary in relation to vehicle performance measures for certain types of multi-combination vehicles.

7.2 Stage 3 - Guidelines

The findings of the reports thus far have supported the need for a set of guidelines to assist owners/operators and trailer manufacturers in specifying suspensions system requirements for new trailers intended for long multi-combination use. To this end, and in conformity with the original terms of reference, the NTC has agreed to financially assist the Australian Road Transport Suppliers Association (ARTSA) to commence production of the guidelines. The guidelines will be available for use by industry free of charge and available from the ARTSA website.

8 Appendices

8.1 Appendix A: Explanation of certain vehicle performance indicators

8.1.1 Yaw Damping

Figure A1 visually explains the meaning of ***Yaw*** as fundamentally a rotational movement around a vehicle's vertical axis. In a moving vehicle *yaw* can vary in both magnitude and direction. Yaw effects are most noticeable when a vehicle has undergone a severe steering manoeuvre such as a sudden lane change. Yawing motion can be exacerbated by poor vehicle design, poor road conditions, unsatisfactory loading techniques, towing another vehicle and by other external factors such as unsteady localized crosswinds. ***Yaw*** is measured in degrees. The yawing motion is described as ***Yaw Rate*** and is measured in degrees per second.

A vehicle with poor yaw characteristics is difficult and uncomfortable to drive and in extreme cases can be dangerous. Modern motor vehicles, including trucks have very good yaw characteristics when driven individually.

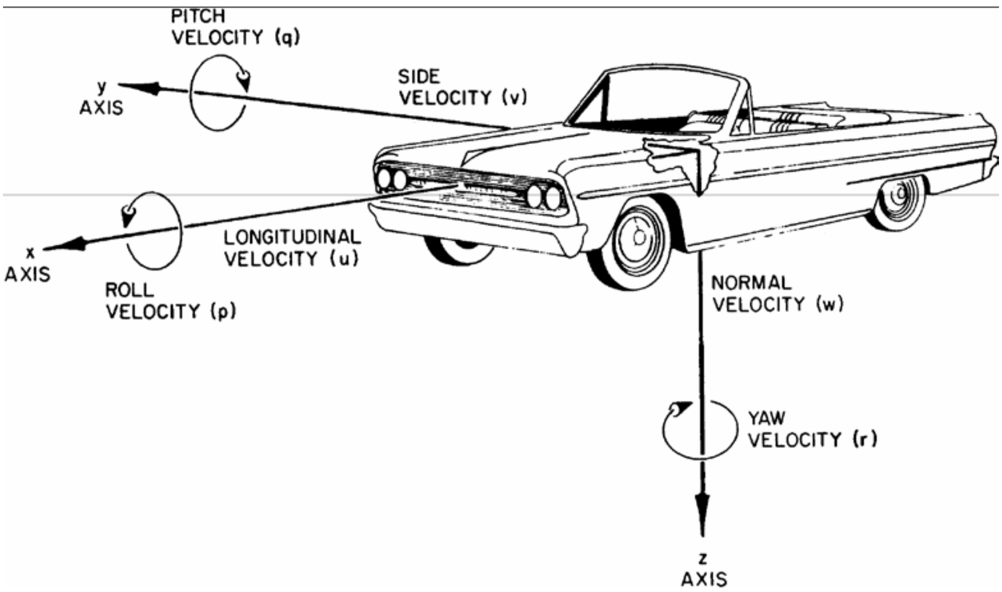

Figure A1 Visual representation of 'Yaw' (Society of Automotive Engineers, 1976)

In multi-combination vehicles however, each trailer can help magnify the affects of yawing by transmitting its rotational movement, through the drawbar, to the following trailer. The ability of either each vehicle, or combination of vehicles, to reduce the yawing motion is known as ***yaw damping***.

Yaw damping in the context of this project is therefore a measure that quantifies how quickly *sway*, or *yaw* oscillations of the last trailer take to settle after application of a short duration steer input at the hauling unit. Vehicles that take a long time to settle

increase the driver's workload and represent a higher safety risk to other road users and to the driver.
Values of yaw damping, are expressed in a term known as the ***yaw-damping coefficient*** – this coefficient has a range from zero to one. A value of 'zero' suggests there is no damping present in the yaw response and in the absence of further application of steering by the driver the oscillations will continue indefinitely. A value of 'one' indicates that the response is rapid and damping occurs instantaneously. Values of yaw damping tend to decrease with speed - at higher speeds therefore, the oscillations may take longer to decay resulting in the potential for rollovers in extreme cases.

The prolonged swaying of the last trailer that occurs as a result of poor damping can also lead to partial, or complete loss of control, increasing the likelihood of a collision with a vehicle in an adjacent or opposing lane or with roadside objects.

Method of evaluation

Yaw damping can be measured by field-testing or it can be determined by computer-based modelling. To determine yaw damping the vehicle is subjected to a short duration input of steering; a very rapid application of steer is applied from the straight-ahead position over a short time period, which is then quickly returned to the straight-ahead position over a time period of similar short duration. In response to this steering manoeuvre, the prime mover will change its direction of travel (its heading) and the trailers will follow. The transition to the new heading is accompanied by yaw (swaying) oscillations of the trailer(s) that diminish in amplitude if the yaw damping is greater than zero. The yaw-damping coefficient is subsequently calculated from these results.

8.1.2 Rearward Amplification

Definition

Degree to which the trailing unit(s) amplify or exaggerate sideways motions of the hauling unit. This is the ratio calculated by dividing the peak sideways acceleration measured at the rearmost trailer in a combination by the corresponding sideways peak acceleration in the prime mover.

Significance

Rearward amplification pertains to heavy vehicles with more than one articulation point, such as truck-trailers and road train combinations. It occurs when a vehicle changes path suddenly – for example a road train having to be suddenly driven around a stopped vehicle in its path.

During manoeuvres of this kind there is a tendency for the rear trailer to have a much larger sideways motion than the corresponding movement in the prime mover that caused it. Drivers of heavy combination vehicles instinctively understand this vehicle behaviour and consequently avoid unnecessary sudden manoeuvres. Apart from imparting large stresses on their vehicles, sudden excessive steering manoeuvres, may cause damage to cargo, and in the case of livestock operators, that can mean injury or death of animals. In extreme circumstances, the amplifying affect can result in a rollover.

Method of evaluation

The vehicle combination is driven along a path set out by the evaluator. The path is set out in accordance with a standard to ensure that all tests carried out this way can be compared to each other with a reasonable level of confidence. Figure A2 visually illustrates the shape of the test path.

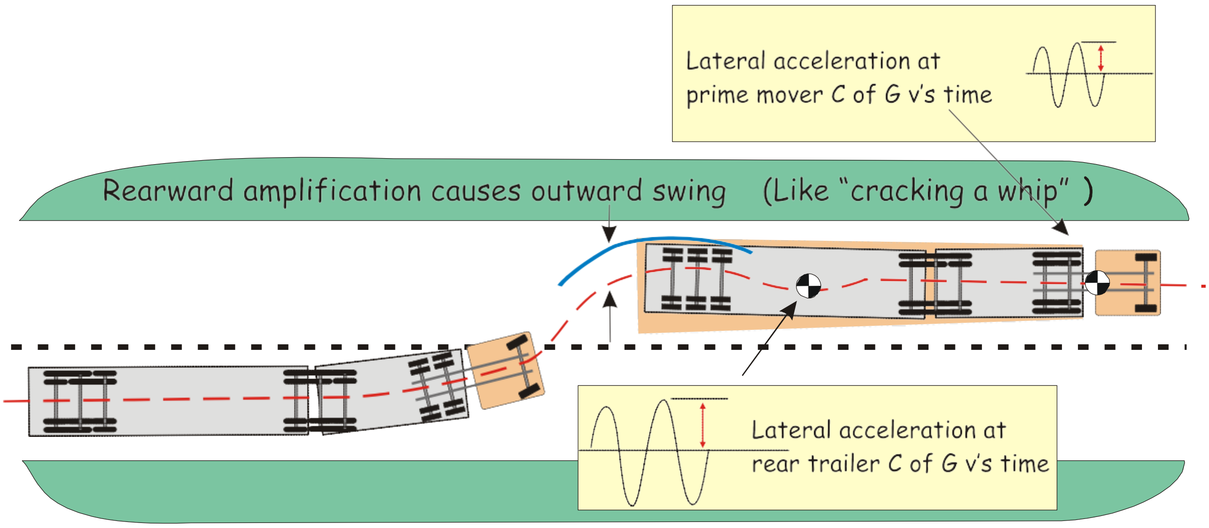

Figure A2 Rearward Amplification (Courtesy of ARTSA)

8.1.3 Lateral Acceleration Gain

In simple terms the ***Lateral Acceleration Gain*** (LAG) curves shown in Figures 4 to 6 and 15 are a form of rearward amplification measured across a range of driver steering wheel inputs (frequency). Unlike *Rearward Amplification*, these measures are not obtained by following a strictly defined path.

LAG is the therefore the ratio calculated by dividing the peak sideways acceleration measured at the rearmost trailer in a combination by the corresponding sideways peak acceleration in the prime mover across a range of steering wheel inputs. In simple terms a high LAG at a particular driver steering input, means the rearmost trailer experiences a sideways acceleration many times greater than that experienced by the prime mover that caused it.

When a person attempts to drive a vehicle in a straight line, the steering wheel is inevitably moved from side to side at various rates – this is a necessary response to keep the vehicle on a straight path as indentations and other road characteristics will cause the vehicle to deviate from the intended straight path. These steering manoeuvres can be described collectively as ***steering inputs***. Each individual steering input has a ***frequency*** which is simply the number of times that steering input can be repeated every second. The frequency values are expressed in Hertz (Hz). One Hz means one cycle per second. 0.4Hz means the cycle takes 2.5 seconds to complete.

In this project Roaduser has used sophisticated data logging equipment that has allowed the collection of data representing the corresponding LAG measured at the last trailer for a wide range of prime mover steering wheel inputs whilst the vehicle was being driven on the road.

Roaduser describes this collection of data as a ‘Frequency response (LAG) analysis’. This collection of data provides the necessary information to create Figures 4 to 6 and 15 in the body of this report.

8.1.4 Summary of Performance Indicators Discussed

Measure	**Measured as**	**Desired Outcome**
Yaw	Degrees	The lower the figure the better
Yaw rate	Degrees per second	The lower the figure the better
Yaw Damping Coefficient	Ratio	0 = extremely poor 1 = extremely good
Rearward Amplification	Ratio	The lower the figure the better
Lateral Acceleration Gain	Ratio	The lower the figure the better

8.2 Appendix B: Terms of Reference Stability and on Road Performance of Multi Combination Vehicles with Air Suspension Systems

8.2.1 Purpose

To improve the on road performance and safety of multi combination vehicles incorporating air suspension systems.

8.2.2 Background

The Northern Territory Department of Transport & Works on behalf of the Remote Areas Group (RAG) commissioned a consultant (Estill & Associates PTY LTD) to undertake a survey into the operational stability and performance of various multi combination vehicle configuration incorporating air suspension systems.

The consultant found that there is considerable concern regarding the on road characteristics and performance of some existing heavy combination vehicles fitted with air suspension systems when compared to the same combinations with steel spring suspension systems.

It was noted however that, at this point in time, there is no evidence that vehicles with air suspensions are over represented in accident statistics. Discussions with industry have confirmed, however, that the majority of trailer rollovers occur in remote areas and many are unreported. For this reason, the absence of reported accident data should not be cause for complacency nor a reason to ignore a potential safety issue, which a number of transport operators have indicated is causing them considerable concern.

8.2.3 Issues

- An increasing focus on the use of air suspension systems on heavy combination vehicles has occurred due to the implementation of higher mass limits under the mass limits review. While this is a desirable outcome for productivity reasons it now requires further work to be undertaken to provide guidance to operators and manufacturers in the best use and application of air suspension systems for various multi combination vehicle types.
- The primary areas of concern relate to multi combination vehicles with air suspension systems that were typically operating at high mass limits with high centres of gravity. As a result, vehicle air suspension modifications were being undertaken to counteract some of the undesirable attributes found with these vehicle types.
- The survey outcome makes it apparent that guidelines for the use of air suspension systems in multi combination vehicles would be a positive safety initiative and of assistance to both manufacturers and operators alike.

8.2.4 Project Requirements

The project will be undertaken in 3 stages with assessment undertaken at the end of each stage prior to commencement of the next.

8.2.4.1 Stage 1

Based on the anecdotal findings of the Estill and Associates report on stability and on road performance of multi combination vehicles with air suspension systems conduct computer simulation and modelling of regulation single articulated, "B" double, double and triple road train combinations of both typical spring and typical air suspension types to establish performance characteristics and performance limits with particular reference to the effect of vehicle centre of gravity, speed, road roughness and product carried.

The Stage 1 report must detail the following Performance measures for each of the vehicle combinations in both typical spring and typical air suspension configuration and make reference to current available suspension modifications that can enhance on road performance.

- Static roll stability
- Rearward amplification
- Load transfer ratio
- High-speed steady-state off-tracking
- Yaw damping
- Tracking ability on a straight path
- Braking stability (in a turn)
- Handling quality (understeer/oversteer)
- Low-speed off-tracking

8.2.4.2 Stage 2

Stage 2 will only be undertaken subject to the analysis of the outcomes of Stage 1 and if warranted and commenced will comprise field trials of the vehicle configurations detailed in Stage 1.

The field trials will require instrumentation of selected vehicle combinations to validate or otherwise the results and performance outcomes detailed in Stage 1.

The field trials may also require assessment of aftermarket modifications.

8.2.4.3 Stage 3

Stage 3 will be commenced following the completion of Stage 1 and if undertaken, Stage 2.

Stage 3 will comprise the development of guidelines detailing best practice application and use of air suspension for single articulated and multi combination vehicles.

The guidelines will draw on the outcomes of Stage 1 and, if undertaken, Stage 2; as well as referencing existing material available from manufacturers, government and industry bodies covering application, selection, design limits and maintenance of air suspension systems.

The guidelines are also to include recommendations as to the: -

- preferred vehicle types and operating conditions for air suspension systems.
- any circumstances in which air suspensions are unsuitable for use with Multi combination vehicles.
- the appropriateness of after market modifications in improving the performance of air suspension systems.

Note: The above Terms of Reference were agreed to by the Remote Areas Group (RAG) members at the RAG meeting held in Dubbo on the 19th February, 2001.

8.3 Appendix C: Acknowledgements

8.3.1 Support from within the WA RAG Focus Group

The following people provided local support, encouragement and financial assistance in progressing the project since its inception.

Howard Croxon	RAG Independent Chairman (1999- 2001) and WA RAG Focus Group representative
Frank Marley	Transport Forum WA (WA RAG representative and WA RAG Focus Group representative). (Agreed to funding on behalf of the Forum)
The late George Freestone	Livestock Transporters Association of WA (WA RAG representative and WA RAG Focus Group representative). (Agreed to funding on behalf of the Association)
Doug McDonald	CVIAA President, CVIA WA representative and WA RAG Focus Group representative
Ian Tarling	Main Roads WA (WA RAG Focus Group representative and Heavy Vehicle Reference Group)
John Mitchell	WA Livestock Transporters Association (WA RACG representative). (Agreed to funding on behalf of the Association for Stage 2 and provided vehicles, a driver and his time for the Stage 2 road train trials)
Bob Peters	Main Roads WA (Mr Peters provided the seed capital that enabled commencement of the Stage 2 project).

8.3.2 Estill Report

Consultant (Estill and Associates Pty Ltd)

Albert O'Neil	Project Consultant

Management Team

Tony Sinclair	Project Manager (Northern Territory Department of Transport and Works)
John Hollins	Project Management Team (Northern Territory Department of Transport and Works)
Jim Cooper	Advisor (Gulf Transport)

8.3.3 Stage 1 Project

Management Team

John Dombrose	Project Manager (Transport WA)
Barry Hendry	Project Management Team (NRTC)
John Hollins	Project Management Team (Northern Territory Department of Transport and Works)
Rex Middleton	Project Management Team (Transport WA)

Consultant Team (Roaduser Systems PTY LTD)

Peter Sweatman	Project Director
Scott McFarlane	Technical Director
Brendan Coleman	Simulation Engineer

Management Committee (As at 10 February 2002)

Mr Ian Lawrie	General Manager	York Transport Equipment
Mr Mark Boon		Holland Hitch
Mr Ken Cowell	General Manager Product Safety	Volvo Truck and TIC Representative
Mr Mario Colosimo	Manager Trailer Equipment Division	Transpec
Mr Andrew Martin	Engineering Manager	Hendrickson
Mr Gary Hartley Mr Phillip Webb		Kenworth Trucks Kenworth trucks
Mr Bob Woodward		Bob Woodward & Associates
Mr Dante Travaglini		Private Consultant
Mr Jim Cooper		Gulf RTA Group
Mr Doug Mc Donald	General Manager	SFM Engineering
Mr Les Bruzsa	Principal Engineer	Queensland Transport
Mr Ian Tarling	Heavy Vehicles Operations Manager	Main Roads WA
Mr Mark Terrell		VSSB DOTARS

8.3.4 Stage 2 Project

Management Team

John Dombrose	Project Manager (DPI WA)
Barry Hendry	Project Management Team (NTC)
Rex Middleton	Project Management Team (DPI WA)

Consultant Team (Roaduser Systems PTY LTD)

Peter Sweatman	Project Director

Robert Di Cristoforo	Technical Director
Marcus Coleman	Test Manager
Anthony Germanchev	Test Engineer

Combined Trials Working Group (Included Stage 2 Road Train Trials and Queensland Innovative Vehicle Trials)
The following members of the Combined Trials Working Group were responsible for organizing the logistics of the combined trials including road selection, road closures, traffic management, vehicle inspection and weighing, vehicle selection and public affairs issues.

Table 10.1 Road Train Trial Working Group Participants

Name	Role	Organization
Des Snook	Chair of Working Group (Executive Director Road Network Services)	MRWA
Rob Harvey	Site Project Manager	MRWA
Dean Roberts	Public Affairs	MRWA
Samantha Johnston	Public Affairs	MRWA
John Rossiter	Heavy Vehicle Operations (Permits)	MRWA
John Marcolina	Heavy Vehicle Operations	MRWA
Garvin De Silva	Heavy Vehicle Operations	MRWA
Greg McFarlaine	Vehicle Inspections & weighing	MRWA
Mark Hobley	Vehicle Inspections & weighing	MRWA
Brian Kidd	Manager MRWA Braking Trials	MRWA
John Fletcher	Asst. Manager MRWA Braking Trials	MRWA
Ian Tarling	Consultant (Vehicle selection and organization)	Consultant
John Dombrose	Manager Stage 2 Road Train Trials	DPI
Rex Middleton	Asst Manager Stage 2 Road Train Trials	DPI

8.3.5 Stage 2 – Combined Road Train Trials (9th to 13th April, 2004)

Table 10.2 lists those who participated in the Stage 2 trials. Whilst the combined trials comprised three individual projects (Stage 2 road train trials, Queensland innovative vehicles trials and the Main Roads (WA) heavy vehicle braking trials) all on-site personnel operated seamlessly providing support to each other. This high level of camaraderie proved to be one of the reasons why these trials were so successful in terms of their organization, quality of data captured and operational safety.

These trials demanded long hours of work commencing very early in the morning and finishing late in the evening. The dedication shown by the consultants and members of each team has been very much appreciated as has the response of industry personnel who supported the trials by offering their time, staff and vehicles.

Table 10.2 Road Train Trial Participants

Name	Role	Organization
Brian Kidd	Site Manager & Manager of MRWA Braking Trials	MRWA
John Fletcher	Site Manager & Assist. Manager of MRWA Braking Trials	MRWA
David Mott	Vehicle Inspections/weighing	MRWA
Rhonda Bywaters	Vehicle Inspections/weighing	MRWA
Michael Griffith	TNC 7 Contact Road Traffic Management	MRWA
John Dombrose	Manager “Stage 2 - Air Suspension Project”	DPI
Rex Middleton	Assistant Manager “Stage 2 - Air Suspension Project	DPI
Peter Sweatman	Director of Road Trials Research	Roaduser Systems Pty Ltd
Marcus Coleman	Field test manager	Roaduser Systems Pty Ltd
Anthony Germanchev	Test engineer	Roaduser Systems Pty Ltd
Chris Hood	Test engineer	Roaduser Systems Pty Ltd
Robert Di Cristoforo	Simulations manager	Roaduser Systems Pty Ltd
Kenny Cann	Test technician	Roaduser Systems Pty Ltd
Ian Tarling	Test Vehicle Manager and advisor	Private Consultant
Les Bruzsa	Manager of Queensland Project and advisor	Queensland Transport
Peter Caprioli	Test Technician	Queensland Transport
Rob Gibson	Test Engineer	Queensland Transport
John Mitchell	Provided his company’s vehicles	M & J Mitchell
Jack Dewar	Driver	M & J Mitchell

John Leeds	Provided his company's vehicles	Leeds Transport
Peter Holmes	Driver	Leeds Transport
Ian and Prue Fullerton	Pilot Operators	
Gary Muntz	Provided vehicles	Mitchell Corporation
Andrew Forte	Provided vehicles	Mitchell Corporation
Carl Cardaci	Provided yard facilities	Centurion Transport
Roy Melor	Provided yard facilities	BGC Transport
Geoff Conway	Provided yard facilities	BGC Transport
Doug McDonald	Provided yard and workshop facilities	SFM Engineering

8.3.6 Attendees of the RAG Dubbo Meeting 19 February 2001

Attendance as shown in the minutes of the RAG Dubbo Meeting.

Attendees

Howard Croxon (Independent Chairman)

Barry Hendry (NRTC), Robin Ide (SA), John Dombrose (WA), Greg Booth (NSW), Tony Sinclair (NT), Graham Baldock (SA), Robert Gunning (ALTA), John Morris (ARTA), Frank Marley (WA), Phillip Halton (Qld), Ron Pattel (Qld), Bill Basket (Qld), Gary Penn (WA) and Jim Cooper (NT).

Observers

Phillip Leeds (RTA), Chris Walker (RTA), Andrew Rankin (ATA), Stuart Peden (RTA), David Anderson (NATROAD), Peter Lewis, George Freestone (WA), Les Bruzsa (Qld), Gary Mitchell (ATN).

Apologies

Gary Mahon (Qld), Stuart Hicks (NRTC), Paul White (NRTC), Andrew Woods (NT) and Jane Wiech (SA).

Secretariat

Rohit Autar (RTA)

8.4 Appendix D - Overarching Project Outline

Project	Stage	Consultant	Report
Field Investigation (Anecdotal Evidence)	N/A	Estill and Associates Pty Ltd	*Operational Stability and Performance of Air Suspensions on various Vehicle Configurations – Estill and Associates Pty Ltd – September 2000*
Principal Project (Scientific Investigation)	**Stage One** Computer Simulations	Roaduser Systems Pty Ltd	*Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems -Stage 1 Project – Roaduser Systems Pty Ltd - 2002*
	Stage Two Road Instrumented Trials	Roaduser Systems Pty Ltd	*Stability and On-Road Performance of Multi-Combination Vehicles with Air Suspension Systems -Stage 2 Project -Roaduser Systems Pty Ltd – January 2005*
	Stage Three Guideline Preparation	Australian Road Transport Suppliers Association (ARTSA)	Under development

8.5 Appendix E - Project Hierarchy