# BIG PRIME MOVERS – WHY DOES AUSTRALIA HAVE SERIOUS PROBLEMS? AND HOW DO WE FIX THEM?

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## ABSTRACT
Australia had experienced significant safety related problems with high powered, long wheelbase prime movers. Yet the same problems have not been documented in USA or Europe. This paper reviews the vehicle engineering problems with very large prime movers that lead to wandering, darting (a very serious road safety problem), degradation of the vehicle components through vibration, degradation of the driver's health through vibration, and fatigue. It further researches the reasons why the problems seem to be restricted to Australia. Finally it details the changes to design likely to eliminate the problems in prime movers built in the future.

## INTRODUCTION
### Problems with heavy vehicles, and the FORS Heavy Vehicle Safety Investigation
Over the past twenty years particular makes or styles of heavy prime mover have been subject to complaints about a range of problems. In recent times there have been several styles of heavy vehicle with specific problems.

For one group of these vehicles the problems have related to wandering, darting, vibration related accelerated wear of components, and/or vibration induced health problems. These problems have been reported since the late 80's, though they appeared to increase in the mid 90's. As a result, the Federal Office of Road Safety (now the Australian Transport Safety Bureau or ATSB) invited expressions of interest and then tenders for the Heavy Vehicle Safety Project in the latter half of 1998. Roaduser International was successful in tendering for the work for an amount of about $90,000, though by the end of the project this had increased to $580,000.

Advertisements with wording similar to that below were placed in transport industry magazines.

**HEAVY TRUCK**
**SAFETY INVESTIGATION**
***Truck owners!***

Roaduser International of Melbourne has been appointed by the Federal Office of Road Safety to investigate vibration and stability of heavy articulated trucks following recent complaints

***If your truck suffers from:***

- **Wandering**
- **Poor handling**
- **Instability**
- **Abnormal vibration**

**Please call Scott McFarlane at Roaduser International (03) 9329 1666**

A total of 30 owners formally responded in relation to 35 vehicles. Contact was made with others who claimed to have the stated problems with their vehicles, but who declined to become formally involved. The most common reasons were that owners did not want to jeopardise their relationships with the dealers/ manufacturers, and drivers did not want to jeopardise their relationships with owners.

Of the 30 owners, 13 of their vehicles were inspected and tested. All were found to exhibit the behaviors that had been complained of, though the degree to which they were perceived to be a problem varied.

And of the 13, five that were representative of the rest were chosen for instrumented testing. (A photograph of vehicle F3, a Kenworth C501 model, that was both inspected and driven, and instrument tested is shown below.) In addition manufacturers supplied three other vehicles as benchmark vehicles.

The final report made 16 recommendations related to the following:

- Action being taken to identify and evaluate prime movers which have safety deficiencies similar to those identified for vehicles in the report, with such vehicles being rectified through appropriate intervention.
- Action being taken to ensure that manufacturers do not build future vehicles that exhibit some problems identified in the report.
- Regulation or other means being considered for controlling characteristics of suspensions, with regard to their influence on handling quality, steering behaviour and vibration;
- Owners of some prime movers being advised of the test results and the need for rectification or restriction to certain types of operation.
- Action being taken to develop robust test methods to identify problems and to develop means of rectification.
- Education and/or publicity material being prepared addressing aspects of the problems identified in the report;
- Industry/government action being launched to develop effective means of contributing to the management of driver health risks in relation to excessive prime mover vibration;
- The relationship between levels of seat vibration, driver fatigue and driving hours being further investigated.
- Research being initiated into the health effects of vibration on truck drivers and the development of relevant standards, the influence of unwanted steering disturbances on driver fatigue, and the effects of prime mover handling on ease of steering control and safe operation under all road conditions;


However a number of technical experts and many of the owners of problem vehicles are concerned about deficiencies in the investigation and or Final Report, and the fact that vehicles that exhibit unsafe characteristics have been left operating on Australian roads.

**APPROACH**

The author was involved in the FORS Investigation while an employee of Roaduser International in 1999, and continued his interest in the investigation after leaving that consultancy. In considering concerns about the investigation and Reports, information and knowledge derived during the time of employment has been used, though confidentiality agreements prevent some of that information and knowledge being presented.

The approach was to consider the degree to which the investigation and recommendations explain

- population characteristics of problem vehicles;
- observations by owners of their vehicle's behaviour;
- the lack of reporting of similar problems in other countries; and
- particular problems with some vehicles.

Aspects of the investigation that may have contributed to failures to determine causes of problems were considered.

**Population characteristics of problem vehicles, and of other large vehicles**

Reference to the Roaduser International reports and knowledge of the operations of the owners of problem vehicles shows that, ignoring two vehicles for which noise was the major problem, problem vehicles have:

- long wheelbases, with all but one of those known being at least 4800 mm, and up to 6150 mm;
- high horsepower engines, with 86% of those known being at least 420 hp, and up to 610 hp;
- predominantly air bag suspended rear axles, being 27 out of 29 vehicles for which information was available;

- mainly Kenworths (44% of owners, 42% of vehicles), Macks (22% and 18%), and Fords (15% and 24%);
- operations or markets requiring curtain-sided trailers or vans, travel on secondary highways, generally high COG loads, and generally at axle mass limits.

The Roaduser International report Appendix Q estimates there are 42000-43500 6x4 prime movers capable of operating at 42.5 tonnes. Further analysis shows only about 7000 - 7500 of these would have wheelbases of at least 4800 mm and engine horsepower of at least 420 hp.

**Observations of owners of their vehicle behaviour**

The owners of the problem vehicles reported a range of problems generally or specifically including:

- wandering – the need for continual steering input to maintain a straight line;
- darting – occasional significant deviations of the vehicle to the left or right, without driver input. These may be to the right or left, though on average the reports suggest that deviations to the right are greater;
- reduced vehicle component life due to vibrations, including engine, cab, sleeper, bonnet and radiator mounts; cab structures, dashboards, shock absorbers, tyres (severe scalloping of steer tyres), and other components;
- symptoms of "vibration" sickness;
- variable behaviour including handling and steering being good on high standard roads/ very poor on secondary highways; good at start of the trip and then deteriorating over time (with relief sometimes achieved by de-coupling the prime mover and taking it for a short trip and re-coupling); and acceptable when tyres and other components new or in new condition and then rapidly deteriorating with kilometres of travel; and
- apparent "jacking up" of the rear axle airbags leading to pounding of the front axle.

**Lack of similar problems being reported in other countries**

In section 5.3 on page 13 of the Report, it is stated that "*FORS approached regulators in US, UK, Canada, Japan, and New Zealand. The UK, Canada, Japan and New Zealand advised that there had been no similar complaints. The US had received one complaint which did not proceed to an investigation."*

**ANALYSIS**

**Poisson analysis of problem vehicle population characteristics**

Poisson analysis of the chance of having 33 out of 35 vehicles belonging to a sub-population which equals 17% of the total population of 42000 vehicles or more shows there is zero chance. Hence wheelbase and engine power or their correlates must be a factor in relation to the vehicle problems being complained about.

Of the long wheelbase high powered vehicle population about 70 % will have air bag suspended drive axles. Poisson analysis of the chance of 2 out of 29 problem vehicles being mechanically suspended when the overall population has 30% mechanical suspensions gives a value of 0.9%, indicating that suspension type or its correlates are relevant to the problem.

Reference to the material in Appendix Q of the Report and other data on truck deliveries suggests the approximate split of high powered long wheelbase vehicles by make shown in the Table below. And Poisson analysis gives the chances of observing the level of complaints shown due to chance alone.

| Make | Drive suspension | | Total | Complainant vehicles | | | Comments |
|---|---|---|---|---|---|---|---|
| | Air | Mech' | | Air | Mech' | Total | |
| Kenworth | 1500 | 1000 | 2500 | 11 | 2 | 13 | 12% chance of 13 complaints or more |
| Mack | 1000 | 500 | 1500 | 5 | 0 | 5 | 63% chance of 5 or more complaints |
| International/Iveco | 1000 | 200 | 1200 | 1 | 0 | 1 | 4.8% chance of 1 or less complaints |
| Other | 1500 | 500 | 2000 | 7 | 0 | 7 | 58% chance of 7 or more complaints |
| | 5000 | 2200 | 7200 | 24 | 2 | 26 | |

The Table suggests that the higher rate of complaints for Kenworth vehicles is unlikely to be due to chance, while the very low rate of Iveco complaints is not due to chance.

**Key factors not explained by the FORS Report based on Poisson analysis**

The report does not contain information or any hypothesis that can explain why:

- Predominantly long wheelbase (>=4800 mm) high horsepower (>=420 hp prime movers have problems;
- Mechanically sprung drive suspensions have a much lower complaint rate than air suspensions;
- Iveco/International trucks have a very low complaint rate for long wheelbase high powered prime movers while Kenworth appears to have a higher complaint rate than other makes;

**Observations of owners and the FORS Report**

The report addresses the owner's observations to the following degree:

- wandering – factors such as roll steer and bump steer plus road surface variations are implicated though there is limited information of hypothesis to explain variations between vehicles;
- darting – bump steer related to steering geometry is implicated for one vehicle. However there is limited general information, and the fact that deviations to the right are greater (if true) is not explained;
- reasons for excessive vibration are not explained, nor are specific problems such as severe scalloping of steer tyres explained;
- driver seat vibration is only recorded in two directions, so full analysis of vibration against Standards cannot be presented. Hence symptoms of "vibration" sickness are not fully analysed;
- variable behaviour is not explained specifically at all; and
- while air bag pressures are recorded and shown to be highly variable from side to side, and there is apparent variation in average rear axle airbag pressures for the same makes, "jacking up" of the rear axle airbags leading to pounding of the front axle is not analysed, nor are hypothesis for such behaviour presented.

**Reasons for lack of similar problems being reported in other countries**

Check with US and European regulators show that:

- In the US,
  - vehicles are driven on the other side of the road, and US designs are not completely altered to reflect the fact the vehicles are operated on the left hand side in Australia;
  - the axle mass limits are very different so that:
    - Fifth wheel lead may be much greater (up to 500 mm – 600 mm) effectively increasing the torsional stiffness of the chassis, and reducing the degree of isolation of the rear axle from the front of the prime mover in respect of torsional forces generated by the trailer;
    - The maximum mass of a single trailer unit is 36.3 tonnes versus Australia's 42.5 tonnes; and
    - Tri axle trailer semi-trailer combinations do not apply
  - Interstate highways are generally rigid pavements of a high construction standard, being smoother and having much less camber than Australian secondary highways; and
  - Vehicle speeds may be much lower, being 88 km/h in some jurisdictions.
- In the UK and Europe:
  - Axle mass limits are very different, again impacting on the factors above;
  - Dimension limits are tighter, so that cab-over prime movers are the dominant vehicles; and
  - High speed roads are generally rigid pavements of a high construction standard, with it virtually being impossible to operate at 100 km/h on secondary highways due to horizontal geometry, road width, and sight distance restrictions

**Deficiencies in the FORS Investigation or Report that contributed to failure to identify sources of problems**

The instrumentation of the vehicles is now considered to have been inadequate by a number of technical experts. The inadequacies include:

- Accelerometers were only fitted to one chassis rail – this is inadequate to show chassis problems relating to twisting. As a result, it was not possible to fully report on chassis performance in the Final Report, as there was no analysis of torsional related chassis problems.
- Only one rear axle was instrumented so load transfer to the front axle could not be shown, et cetera
- The instrumentation of the vehicles was inadequate to fully show driver seat vibration problems with side to side vibration not being recorded, so full analysis in relation to whole body vibration could not be undertaken;
- The front axle was not instrumented to show side to side roll related movements or loads on the front axle so that roll centre related problems, or loading of the front axle problems could not be analysed; and
- A number of sensors failed during testing so that results for some tests were incomplete.

The major reason for the lack of sensors was that Roaduser International decided to limit the number of channels of data to 32 this was the limit of their existing data-acquisition equipment.

Further deficiencies related to the fact that:

- The trailer used was not torsionally rigid, being a flat top trailer, so differential twisting of the prime mover chassis would have been reduced;
- The vehicles were not operated at their 42.5 tonne mass limit, having GVM's during testing of 38.2-40.6 tonnes.
- The load used did not have a high COG, being 200 litre drums in which sand had been placed. The COG is estimated as being only about 600 mm above the floor of the trailer;
- F1 was tested with brand new front tyres and rims, so that problems resulting from rapid wear of the front tyres could not be observed;
- No effort was made to confirm or refute claims of owners of low component life by reference to owner and manufacturer paperwork – hence the degree to which problems were abnormal was not confirmed;
- Graduates undertook much of the data analysis with little practical experience of truck construction, behaviour and dynamics. Hence there is the potential that adjustment of data for drift or other "irregularities" may have been inappropriate and/or "information" within the data may have been missed or not understood; and
- The investigation (and the implementation of the recommendations since) without due cause gave preference to the input, involvement and statements of the manufacturers over the owners of the vehicles.

**HYPOTHESIS RE CAUSES OF PROBLEMS**

Analysis by the author and other technical experts suggests that the systemic problems with these vehicles are due to chaotic behaviour generated by:

- low torsional rigidity of light weight long chassis (combined with variableness in cross member design) allows high degrees of twisting within the prime mover chassis – calculations show a steady pull of around one tonne would be required to develop a 5 degree twist between the front to back axles. However application of a cyclic force of less than one tenth of this at 1.5 – 2.5 Hz achieved similar twist on two vehicles;
- high engine power has resulted in elevation of cabins and sleepers so floors of cabins are up to 350 mm above the chassis. These structures which may weigh up to 2 tonnes then act to generate significant moments around the flexible chassis, and combined with natural frequencies similar to the chassis roll frequency and rear suspension natural frequency are predisposed to chaotic behaviour in roll and pitch;
- high engine power applies high engine torque to the engine mounts and the flexible chassis and can drive higher frequency vibrations;
- variations in air bag pressures resulting from poor air bag height control system design:
  - distort the rear suspension and alter rear suspension wheel alignment dynamically, leading to forces being generated to steer the front of the prime mover to one or other side; and/or
  - result in load shift between prime mover axles so that the front axle is loaded up (and road damage is significantly increased).
- In at least one vehicle the air compressor size had not been designed to cope with the air flow demands of a twin height control valve (HCV) prime mover system and trailer air bag system so that progressive loss of system pressure led to soft air bags, greater movement of air bags, increased air flow through the HCV's …[European design vehicles which have very sophisticated air control systems to the air bags don't appear to have the problems of the American style designs which have very simple systems (though statistical analysis reveals this could be explained largely by chance – the analysis is inconclusive)];
- Torsionally rigid trailers combined with higher COG loads at axle mass limits with the fifth wheel lead being only 100 mm to 200 mm, plus a flexible chassis, result in the drive axle group and the trailer acting as a rigid unit and encourage cyclic twisting of the prime mover chassis on lower standard roads; and
- High heavy engines and high heavy cabins have raised the roll centre of the front of the prime mover to the degree that front shock absorbers have limited effect on stopping cyclic roll motion, and tyres are subject to considerable side squirming forces.

The hypothesis is supported by:

- The work undertaken by Jim Searle of Sunshine Van Repairs in "fixing" problem vehicles by modifications and adjustments to the airbag control system, plus fitting high performance shock absorbers. This ensures the air bag

control system works as designed, with minimised air bag pressure variations (stops or helps to stop the initiation of chaotic behaviour) and increases the chances that shock absorbers will prevent chaotic behaviour;
- The work of Bill Haire of Haire truck and Bus Repairs in fixing problem vehicles including F6, by dramatically modifying the air bag system and control system so that air bag pressure variations are minimised, load sharing is maintained, and air bag system demands for air are minimised;
- The fact that Iveco/International, which undertakes comprehensive testing in Australia in the development of heavy vehicles, does not have a significant problem. Chassis design is more conservative (and hence heavier, a market disadvantage) with double railing applying for wheelbases of 5000 mm or greater, and well designed cross members. Cabin heights are generally lower, and mounting better in preventing roll and pitch and driver vibrations. And the degree to which customization is allowed is closely controlled. These all combine to identify and then reduce/eliminate the initiation of chaotic behaviours; and
- The fact that these factors fit with the problem vehicle population.

**CONCLUSIONS**

Australia has serious safety problems with some high horsepower long wheelbase prime movers that include wandering, darting, and vibration induced component damage and driver health and fatigue problems.

These problems are the result of a tendency for chaotic behaviour of the prime movers, encouraged by light torsionally flexible long chassis; raise heavy cabins and sleepers; large, high, and heavy high powered motors; torsionally rigid trailers carrying high COG loads at axle mass limits; and other factors, including high levels of customization without comprehensive testing and development in Australia on secondary highways at 100 km/h.

The problems would be reduced/eliminated for new models by comprehensive testing and development in Australian conditions, with a major part of that development relating to identifying and rectifying chaotic behaviours. And problems with existing vehicles may be fixed by a range of treatments, provided such treatments significantly reduce or eliminate initiation of chaotic behaviour.

Postscript: The required change in attitude by some manufacturers to ensure problems were eliminated would be encouraged by a more proactive and courageous vehicle standards bureaucracy and a more critical truck industry media (it has proved virtually impossible to get the information above into the mainstream truck media, whereas manufacturers regularly have press releases printed without checking the facts in any way.

**ACKNOWLEDGEMENTS**

The ongoing input of the following persons is acknowledged:
- vehicle owners including Rod Millar (owner of vehicle F1), Greg Millar (owner of vehicle F3), John Bauer (owner of vehicle F4), Des Taylor (owner of vehicle F6 and four other “sister” vehicles), Graham Lowe (owner of vehicle F26), and John Boundy (owner of vehicle F30);
- The technical input and research undertaken by Dr Arnold McLean of the University of Wollongong ;
- The input of Jim Searle (Sunshine Van Repairs) and Bill Haire (Haire truck and Bus repairs) in relation to work they undertake in fixing problem vehicles; and
- The input of bureaucrats involved in the vehicle standards areas that maintain an open mind to truck problems and investigations and outcomes.

**REFERENCES**

*Investigation into the Specification of Heavy Trucks and Consequent Effects of truck Dynamics and Drivers Final Report,* A Federal Office of Road Safety Report prepared by Roaduser International Pty Ltd, 2000