

THE EFFECTS OF SAFETY CHAINS ON THE DYNAMICS OF TRUCK AND DOG TRAILER COMBINATIONS IN THE EVENT OF A COUPLING FAILURE

Mechanical Engineering Graduate (Hons) of RMIT University, 2005. Held several heavy vehicle dynamics research and consulting roles in Australia and Germany. Joined Advantia in 2014 where he is currently a Senior Engineer.



ADAM RITZINGER
Advantia Transport Consulting
Australia



Obtained B.E. Aero (Hons) from RMIT University in 1998. Is an expert in heavy vehicle dynamics, policy and regulation, safety and infrastructure performance, and technology. Founded Advantia in 2008, and is its Managing Director

ROB DI CRISTOFORO
Advantia Transport Consulting
Australia

Graduate of Melbourne University with a Bachelor of Science (Mech) in 2012 and a Master of Engineering (Mech) in 2015. Joined Advantia in 2015, where he is currently an Engineer.



DANIEL NOLAN
Advantia Transport Consulting
Australia

ABSTRACT

This paper describes an investigation of the effects of safety chains on the dynamics of truck and dog trailer combinations in the event of catastrophic failure of the primary pin coupling. Safety chains on drawbar couplings are not mandatory in Australia for such combinations, but are recognised as having the potential to reduce crash risk and severity of crash outcomes. Some industry stakeholders, predominantly drivers, have expressed safety concerns regarding potential unintended effects of the chains on the dynamics of the hauling unit in the event of a coupling failure. The on-road dynamics of truck and dog trailer combinations connected only by safety chains was assessed via field tests, in which dynamic performance data was recorded using a data logging system. Through analysis of the recorded data and observations made by the driver of the vehicle and other observers, it was found that neither the truck nor the trailer demonstrated unsafe behaviour in any of the tested manoeuvres. It was determined that a truck-trailer combination can be brought safely to a stop in the event of a primary connection failure, up to the highest tested speed of 80 km/h. These findings strongly indicate that there is little potential for safety concerns to arise as the result of the fitment of safety chains to drawbar couplings of these truck configurations.

Keywords: Truck, Trailer, Safety, Chain, Dynamic, Stability, Coupling, Failure

1. Introduction

At the time of writing, safety chains on drawbar couplings are not mandatory in Australia for truck and dog trailer combinations, but are recognised as having the potential to reduce crash risk and severity of crash outcomes in scenarios involving catastrophic failure of the primary pin coupling. Some industry stakeholders, predominantly drivers, have expressed safety concerns regarding potential unintended effects of the chains on dynamics of the hauling unit in the event of coupling failure. The main concern is that the trailer could become unstable and may either contribute to, or directly cause, loss of control or rollover of the truck. An Australian transport company considered fitting safety chains to its Australian fleet, and engaged Advantia to determine whether the concerns raised are justified. A literature search on this topic did not yield anything, indicating that the research topic is somewhat unique.

2. Investigation aims and method

The aims of the investigation were to determine whether a truck and dog trailer combination can be brought safely to a stop in the event of a primary connection failure; analyse vehicle combination stability in a range of scenarios covering speed, load configuration, road surface conditions, turning/cornering manoeuvres, acceleration and deceleration; and determine the most adverse scenario under which the vehicle combination can be safely stopped in the event of a primary connection failure.

A field test method was chosen over other possible methods (e.g. numerical modelling of vehicle dynamics), due to its real-world applicability and capacity to capture the numerous characteristics that influence dynamic stability, which are at the heart of the concerns raised by drivers. The methodology focused on comparing the on-road dynamics of a typical truck and dog trailer combination (referred to henceforth as the ‘baseline’ vehicle) in a range of normal driving scenarios, against the dynamics of the same vehicle in the same scenarios, but with the trailer un-coupled, and connected only by safety chains (referred to as the ‘un-coupled’ vehicle). Some tests simulated coupling failure while in motion using an automatic release mechanism.

2.1 Test vehicle

The transport company provided a representative truck and dog trailer for use in the field tests. It comprised a three-axle straight truck and a four-axle trailer, both fitted with tanker bodies (Figure 1). The truck was fitted with a new pin-type coupling, featuring a unique remote release mechanism installed by the transport company’s maintenance contractor. The mechanism allowed the pin coupling to be disengaged by activating a switch located within the truck cabin, which could be done while in motion. The coupling was also fitted with two 780 mm long safety chains manufactured and installed by a reputable local supplier (Figure 2). The chains were crossed underneath the coupling, as recommended by the supplier, to support the drawbar and also to limit lateral movement.

The truck was fitted with an anti-lock braking system, and the trailer was fitted with a load proportioning braking system, with no anti-lock capability. Neither the truck nor the trailer were fitted with an Electronic Stability Control (ESC) system. This brake system specification is fairly typical for this type of vehicle in Australia, but represented the worst-case vehicle in terms of brake system performance for that company, as most other vehicles are fitted with an ESC system. The vehicle was tested at two load scenarios: fully laden (with water) to

maximum legal axle loads, and partially laden to represent the least-stable legal and operationally feasible load.



FIGURE 1 – Test vehicle



FIGURE 2 – Pin-coupling, release mechanism and safety chain arrangement

Because of the expected safety risks and unknowns associated with the field tests, tests were undertaken at a privately-owned vehicle proving ground, which allowed the safety risks to be mitigated as far as practicable. The largest safety risk was vehicle rollover or collision with a person or fixed object. To address this, the tests began with initial observations of the combination driven in a straight line at walking pace with the pin coupling disengaged, and the service brakes applied gently to stop the vehicle. When no unsafe vehicle behaviour was observed after several repeat low-speed tests, vehicle speed was gradually increased, and the remainder of the tests conducted.

All tests were conducted on the ‘highway circuit’ at the test facility. The highway circuit was considered to be the best of the available facilities, as its surface texture, roughness profile and geometry are similar to a typical Australian rural highway. The highway circuit is 4.2 kilometers long, and comprises two 3.8-metre) wide lanes on the straight sections, and an extra lane at each curve, giving a total width of 11.2 metres on the curves.

2.2 Test manoeuvres

Seven test manoeuvres were conducted on the baseline and un-coupled vehicles. These included straight line travel at constant speed, controlled braking, negotiating curves, swerving, pulling over and stopping (i.e. emergency braking), disengaging the coupling while travelling in a straight line at constant speed, and disengaging the coupling while cornering at constant speed.

The aim of the swerving tests was to determine whether any unsafe dynamic performance resulted from the event that the driver was required to swerve to avoid an object. For those tests, the driver was instructed to move the combination rapidly to the adjacent lane, and then back again, after a short travel distance. These tests were not conducted to any particular standard, but were controlled to the extent that results from subsequent tests were comparable.

The matrix of tests and tested speeds for each of the load scenarios and coupling configurations is shown in Table 1. Tests could not be conducted at speeds higher than 80 km/h due to the length of the highway circuit’s straight sections and the vehicle’s acceleration capability. The listed speeds were the target speeds for the tests; actual tested speeds varied by up to ± 5%.

TABLE 1 – Matrix of tests conducted

Tests	Full load (km/h)		Partial load (km/h)	
	Baseline	Un-coupled	Baseline	Un-coupled
Straight-line travel	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Straight-line braking	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Negotiating curves	20, 40, 60, 80	20, 40, 60, 80	60, 80	20, 40, 60, 80
Swerving	20, 40, 60	20, 40, 60	40, 60	40, 60
Disengaging coupling – straight line at constant speed	40, 60, 80		60, 80	
Disengaging coupling – cornering at constant speed	60		60	

2.3 Test equipment and data logging

The test vehicle was fitted with a field data acquisition system. The system comprised a computer-controlled data logger that recorded data from various sensors fitted to the test vehicle. The system continuously recorded the speed and position (i.e. latitude and longitude) of the truck, the lateral, longitudinal and vertical acceleration of the sprung mass of the truck and trailer, and the yaw rate of the truck and trailer.

The system also included two high-definition video cameras. The sensor data was collected at sampling rates higher than the expected highest frequency of the signals being sampled. This was done to reduce the risk of data being unintentionally cut-off by the logging system. Sensors with an appropriate measurement range and resolution were used.

2.4 Data processing and analysis

Data processing involved two steps, firstly zeroing the data using static offset values recorded while the vehicle was parked on flat ground without the engine running. Secondly, the data was filtered using a second-order, low-pass ‘butterworth’ filter with a 5 Hz cut-off frequency and a sampling rate of 200 Hz. The filtering removed the high-frequency noise that can obscure the low-frequency measurements of interest. The driver was also interviewed during and after each test to capture his feedback on the vehicle’s behaviour, and feedback provided by the vehicle to him indicating the effects of safety chains on the dynamics and behaviour of the vehicle.

3. Results and discussion

3.1 General observations of vehicle behaviour

The coupling was initially disengaged while the combination was parked on flat ground. The combination was driven at walking pace while the movement of the drawbar eye and trailer were carefully observed.

While the combination was in motion at low speed, the trailer appeared to track a similar path to the truck, and no adverse behaviour was observed, with the exception of trailer alternately shunting the truck in both the fore and aft directions as the slack in the chains was taken up.

At 20 km/h the trailer was observed to slightly ‘wander’ laterally (i.e. from left to right on the roadway), when the chains were slack. The extent of lateral movement in all cases was limited by chain length and the location of the chain attachment points, such that the range of motion of the drawbar eye resembled an irregular shape, approximated in Figure 3.

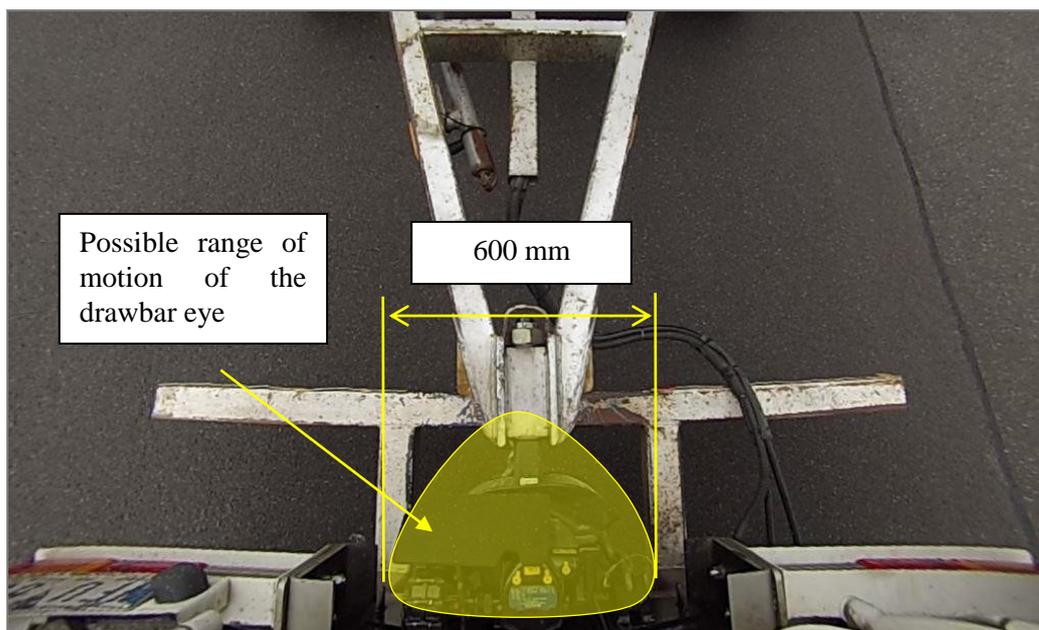


FIGURE 3 – Observed possible range of motion of the drawbar eye

The magnitude of the trailer wandering was not sufficient to prevent it from being effectively towed by the truck, and again, no adverse performance was observed, with the exception of the shunting, the magnitude of which was slightly higher at higher speeds. At 40 km/h and above, the trailer exhibited movements similar to those observed at 20 km/h. The driver of the

truck highlighted the shunting of the truck by the trailer as the key indicator that the trailer was no longer coupled to the truck, and commented that in all cases it could not possibly go unnoticed.

Surprisingly, this behaviour was noted by observers of the test program as being difficult to discern, and they highlighted that there were very few visual cues that it was occurring. Observers noted that the wandering of the trailer was slightly more noticeable than the shunting, but still not obvious. The trailer tended to wander less when cornering than when driving straight. The driver noted the wandering of the trailer as being a far less obvious indicator than the shunting, as the only cues available to him that the trailer was uncoupled were the motion of the trailer visible in the side mirrors.

When braking from speeds between 40 km/h and 80 km/h the driver indicated that the shunting was the main effect experienced, but again noted that it did not affect the handling of the truck, and that it was still safe to pull over and stop in an emergency. The driver noted the tendency of the trailer to ‘dive’ to the left when the brakes were applied more heavily than normal. This behaviour was reasoned to be due to slight differences in brake effectiveness at each wheel. It did not occur consistently, and was not considered to be a safety concern.

Similarly, no unsafe performance was noted as a result of the driver undertaking the swerving manoeuvres. Trackside observers noted that any difference in performance between the baseline and un-coupled cases was difficult to discern. The driver also made comments to that effect. Nevertheless, no swerving manoeuvres were conducted at speeds higher than 60 km/h, due to limited trailer stability in both the baseline and un-coupled scenarios.

Disconnecting the coupling while the combination was in motion, either when travelling straight or while on a curve, appeared to result in behaviour no different to that described previously. The only difference was that the truck was initially subjected to a rearward tug by the trailer as the chains were pulled taut following the release of the coupling.

When partially laden, the combination demonstrated the same overall behaviour as the fully laden vehicle in all of the manoeuvres tested. The driver was asked specifically if the movement of fluid in the tank barrels resulted in any noticeable difference in the behaviour of the truck or the trailer, and indicated that the shunting was lower, reasoned to be due to the reduced payload mass. There were no other discernible effects on the stability of the combination.

3.2 Data analysis

Figure 4 shows the Probability Density Functions (PDF) of the longitudinal accelerations for the truck and trailer in baseline and un-coupled configurations, when travelling at 80 km/h. Comparing the shapes of the density functions provides insights into the relative behaviour of the combination in the baseline and un-coupled scenarios. The plots are very similar in terms of their overall shape, indicating that there is no substantial difference in the range of longitudinal accelerations experienced between the baseline and un-coupled combinations.

The functions for the baseline truck and trailer (i.e. the blue lines) are slightly taller and narrower, indicating that when coupled, the truck and trailer will spend a slighter higher portion of time at very low levels of longitudinal acceleration. In contrast, the functions for the un-coupled truck and trailer (i.e. the orange lines) are shorter and slightly wider, indicating that when connected only by the safety chains, both the truck and trailer are more likely to

experience a wider range of longitudinal accelerations. In practical terms however, these differences are minor, and point towards the only difference between the baseline and un-coupled scenarios being the shunting of the truck by the trailer when un-coupled. The general observations made support this finding.

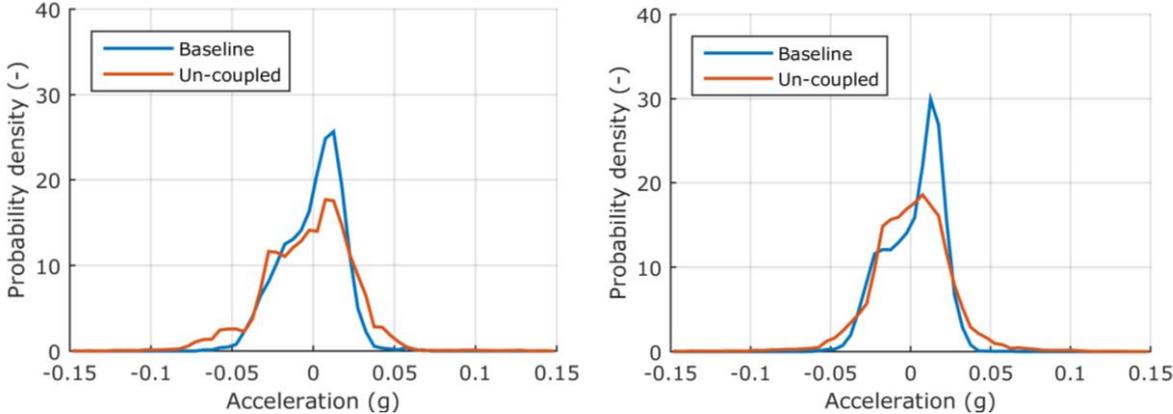


FIGURE 4 – Probability density functions of longitudinal accelerations for the truck (left) and trailer (right) travelling at 80 km/h

Figure 5 shows the PDF of the lateral accelerations for the truck (left) and trailer (right) of the baseline vehicle and un-coupled vehicle, when travelling at 80 km/h (approximately 50 mph). Again, comparing the shapes of the functions provides insights into the relative behaviour of the trailer in the baseline and un-coupled scenarios.

The key result is that the shape of the functions for the truck and trailer are nearly identical in both the baseline and un-coupled scenarios, indicating that there are negligible lateral acceleration effects for either the truck or trailer as a result of the disconnected coupling, and the observed tendency of the trailer to wander causes a negligible lateral acceleration increase for the truck. Numerical results of Root-Mean-Square (RMS) and peak values for longitudinal and lateral acceleration of the fully laden vehicle are shown in Table 2.

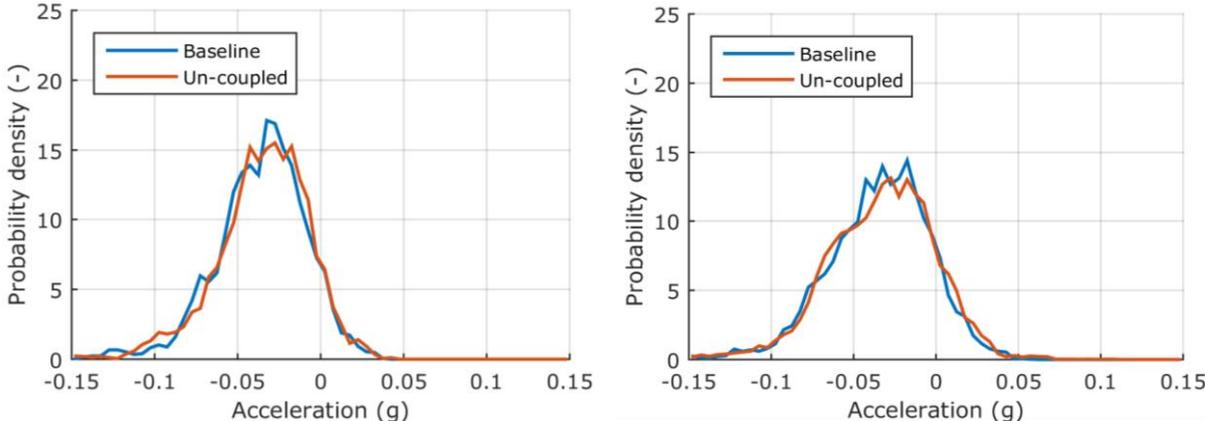


FIGURE 5 – Probability density functions of lateral accelerations for the truck (left) and trailer (right) travelling at 80 km/h

TABLE 2 – Numerical results of various parameters for straight-line travel

Value	Parameter	Truck		Trailer	
		Baseline	Un-coupled	Baseline	Un-coupled
RMS	Longitudinal accel. (g)	0.018	0.033	0.017	0.034
	Lateral accel. (g)	0.045	0.044	0.046	0.047
Peak	Longitudinal accel. (g)	0.069	0.524	0.062	0.606
	Lateral accel. (g)	0.146	0.152	0.155	0.169

The following statements can be made regarding the numerical results:

- Un-coupling causes the truck and trailer to experience RMS longitudinal accelerations that are twice as high as the baseline.
- Un-coupling causes the truck and trailer to experience peak longitudinal accelerations that are between 7 and 10 times higher than the baseline.
- Un-coupling causes negligible difference in the lateral acceleration of either the truck or the trailer.
- Un-coupling causes the trailer to experience peak yaw rates that are twice as high as the baseline, however the truck is relatively unaffected.

The peak longitudinal acceleration values experienced as a result of the fore/aft shunting are similar to theoretical peak values that could be experienced in an emergency braking scenario, but due to their impulsive nature (i.e. a short, instantaneous application) they feel more severe to the driver. The numerical results for cornering were largely similar to those presented above for straight line travel.

The primary effect on vehicle dynamics when braking from a constant speed was again the tendency of the trailer to shunt the truck from behind, which generally occurred if the chains were either slack, or taut in the rearwards direction when the truck's brakes were applied. Figure 6 shows a plot of the longitudinal acceleration experienced by the truck during a braking manoeuvre, for the baseline and un-coupled scenarios, from an initial speed of 60 km/h. The start of the braking period is annotated.

The baseline vehicle achieves a peak initial deceleration of between 0.4 and 0.5 g, which reduces slightly as the driver modulates brake pedal force and brings the vehicle to a stop. In contrast, the deceleration of the truck for the un-coupled vehicle follows a similar slope, but is interrupted by the shunt from the trailer. This is evident as a positive spike in the acceleration plot, and is annotated by the shaded red box. The lower magnitude of peak acceleration in the un-coupled case is simply a matter of the driver having applied different amounts of brake pressure in different tests.

Nevertheless, there were no increases in lateral acceleration or trailer yaw rate as a result of the shunting. This finding supports the observations made by the driver that the shunting action is unlikely to cause the combination to jack-knife under heavy application of the brakes.

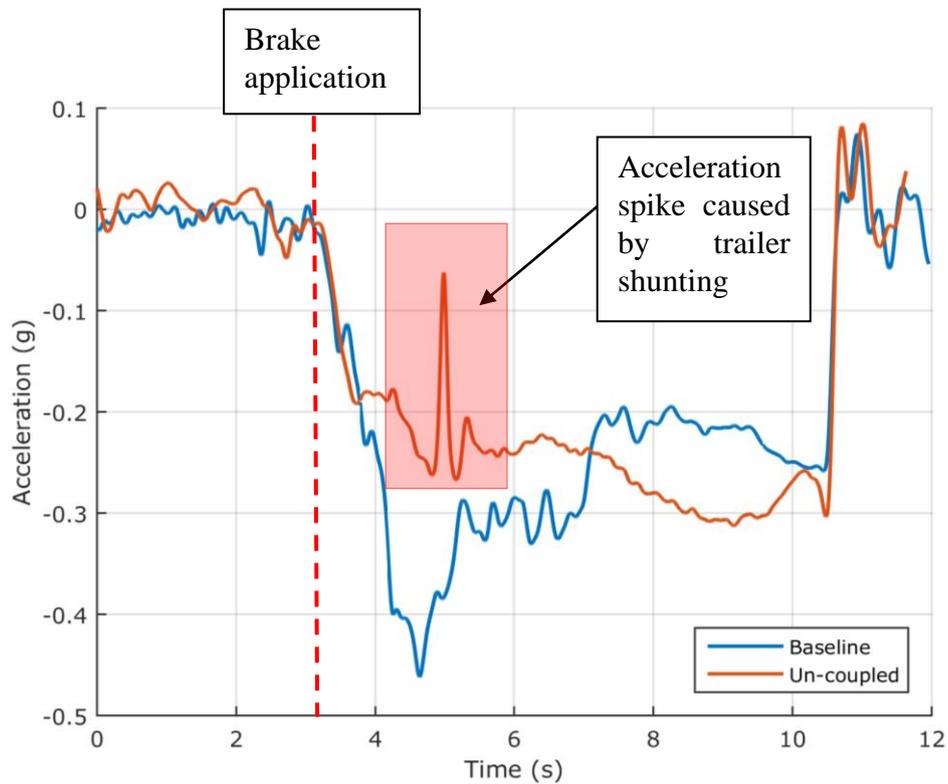


FIGURE 6 – Truck longitudinal acceleration during braking from 60 km/h

Figure 7 shows plots of the lateral acceleration experienced by the truck and trailer during the swerving manoeuvre, for the baseline and un-coupled scenarios, conducted at 60 km/h. The plots show that the un-coupled trailer experienced a marginally higher lateral acceleration than the baseline trailer during the swerving manoeuvre. This was not identified by the observer group or the driver, as the difference was difficult to discern by eye.

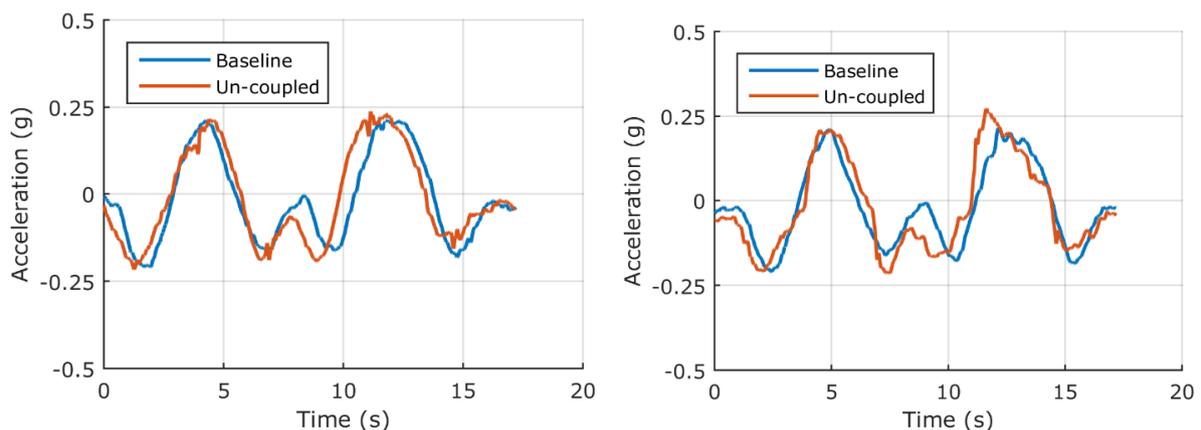


FIGURE 7 – Lateral accelerations for the truck (left) and trailer (right) at 60 km/h

The numerical results of the peak values for the above parameters are shown in Table 3. It should be noted that this data is intended to provide an indication of the differences in peak lateral acceleration and yaw rate for the baseline and failed coupling scenarios, rather than the absolute maximums which were experienced.

TABLE 3 – Peak values of lateral acceleration and yaw rate during the swerving manoeuvre

Parameter	Truck		Trailer	
	Baseline	Un-coupled	Baseline	Un-coupled
Peak lateral acceleration (g)	0.16	0.19	0.16	0.21
Peak yaw rate (deg/s)	4.42	5.64	4.76	6.97

The following statements can be made regarding the numerical results:

- The trailer experiences the same peak lateral acceleration as the truck for the baseline configuration, but a slightly higher lateral acceleration than the truck for the un-coupled configuration.
- The trailer experiences a slightly higher peak yaw rate than the truck in both the baseline and un-coupled configuration.

An increase in both peak lateral acceleration and peak yaw rate of the trailer is expected for this type of manoeuvre when the trailer is uncoupled. The magnitudes of the peak values are within the range expected for this type of vehicle in normal operational configuration. A typical truck and dog trailer combination commonly assessed by Advantia under the Performance Based Standards Scheme (1) experiences peak lateral accelerations of more than 0.30 g and peak yaw rates of around 8-13 degrees per second in a standard “lane change” manoeuvre.

The coupling was released while in motion in order to determine whether its release resulted in any additional effects on vehicle dynamics and handling, as all previous tests had begun with the coupling disengaged while the vehicle was stationary. When disengaged while in motion, the test data showed that the trailer experienced slightly higher longitudinal accelerations after the coupling was disengaged. There were no other effects observed as a result of disengaging the coupling at speeds up to 80 km/h.

4. Conclusion

The objectives of this project were to determine whether a truck and dog trailer combination can be brought safely to a stop in the event of a primary connection failure, and the most adverse scenario under which the combination can be safely stopped.

The field test program addressed these objectives. The general observations made during the field test program provided robust evidence regarding the overall dynamic behaviour of the truck and trailer. The numerical results quantified the level of the effect of the disconnected coupling and provided certainty in relation to the findings from the observations.

The key finding was that when un-coupled, the drawbar eye had a limited range of motion within the constraints of the chains, which permitted the trailer to alternately push and pull the truck while driving, and to sway from left to right on the roadway. Neither the fore-aft shunting, nor the left/right wandering affected the handling or dynamic behaviour of the truck in an unsafe manner, nor did it reduce the level of control that the driver had over the truck in terms of steering or braking. In all tested scenarios where the combination was driven with the coupling disengaged, and where the coupling was disengaged while the vehicle was in motion,

the driver was able to continue operating the vehicle safely, and pull over and stop when directed.

On this basis, it was considered that the first of the project's objectives was achieved; that a truck and dog trailer combination can be brought safely to a stop in the event of a primary connection failure, up to the highest tested speed of 80 km/h. The most adverse scenarios tested involved swerving from left to right (and vice-versa) while travelling at 60 km/h, and emergency braking from 80 km/h. No swerving manoeuvres were conducted at speeds higher than 60 km/h, due to limited trailer stability in both the engaged and disengaged scenarios. Test speeds were otherwise limited by the constraints of the test facility as opposed to concerns regarding vehicle stability.

Although speeds higher than 80 km/h were not tested, speeds higher than 80 km/h (up to the maximum legal road speed in Australia of 100 km/h) are not considered to have the potential to cause vehicle instability or reduce the ability of the driver to control the vehicle and bring it safely to a stop in scenarios where the primary connection fails. These findings strongly indicate that there is little potential for safety concerns to arise as the result of the fitment of safety chains to drawbar couplings of truck and dog trailer combinations.

5. References

1. National Transport Commission. *Performance-Based Standards Scheme – the Standards and Vehicle Assessment Rules*. National Transport Commission, Melbourne, Australia, 2007.