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HEAVY VEHICLE SAFETY INITATIVE ROUND 6

Stability of safety chain coupled combinations

Document number:
ATC2127-01-02

Date:
2 September 2022

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About Advantia

Since its foundation in 2008, Advantia Transport Consulting has specialised in assessing the performance of high-productivity freight vehicles. Advantia now boasts over a decade of heavy vehicle performance intellectual property and has developed an international profile as experts in mechanical engineering simulation and assessment, and for supporting the expansion of freight productivity. Advantia has since gone beyond mastering the design and assessment of high-productivity freight vehicles, having made significant contributions in areas such as heavy vehicle policy development, road access facilitation and knowledge transfer. Advantia is recognised across both the heavy vehicle industry and transport-related government departments and agencies for the specialised work that it does to advance the productivity and safety of road freight transport, primarily by supporting transport policy reform and improved heavy vehicle operations. The company is known for its tenacity and a deep motivation to push boundaries when the evidence supports it. That spirit has enabled the company to make an everlasting impression on Australia's heavy vehicle industry, which is acknowledged internationally.

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Executive summary

This investigation involved the testing of 5-axle and 6-axle dog trailers in various operational scenarios, being towed by a typical 3-axle rigid tipper truck. This research contributes to a research program in which similar methodology was used to test a 4-axle dog trailer combination.

The testing has taken place at the Australian Automotive Research Centre proving ground near Anglesea under controlled conditions, both unladen and laden to capacity. The heavy vehicle combinations were instrumented and filmed at speeds of up to 80 km per hour. Manoeuvres included acceleration, cornering and breaking exercises. The investigation sought to find out how the trailers would behave when connected only using safety chains, including the deliberate disconnection of the Automatic Pin Coupling while underway at various speeds.

The heavy vehicle combinations were safe and stable in all operational scenarios that were tested. Peak forces were within the capacity of the chain and chain attachments. Some fitment geometric criteria could be inferred from the results - including the importance of crossed chains and ensuring the chain attachment points are fitted close to the coupling points on suitably supported structural substrates.

Contents

1. Introduction

Safety of high productivity vehicle combinations

Heavy vehicle trailer separations have the potential to result in death, serious injury and damage to property and infrastructure. Due to the high visibility, destruction and disruption associated with these events, any heavy vehicle trailer separation can also reduce the community's confidence in heavy vehicle safety.

Incidents occur relatively frequently, and a number of high-profile events have occurred in recent years to highlight the opportunity for improved system safety. Anecdotal evidence suggests that in addition to the known incidents that occur in populated or busy areas, a large number of incidents occur that are not reflected in incident data. These incidents can be categorised as:

- not reported (operator seeks remedy without police or insurance involvement, such as on a remote country road)
- not recorded on a database that can be used to collate incident statistics
- not suitably coded in order to accurately determine the mechanism of failure.

Some misconceptions exist within industry regarding the use of safety chains, including fear around the stability of the truck and trailer combination connected only by safety chains in the event of primary coupling failure. Testing previously conducted by Advantia has helped to increase confidence in the use of safety chains. This testing took place with a truck and 4-axle dog trailer configuration. The success of this earlier testing prompted a desire to also test heavier vehicle configurations.

To address this need for additional research, round six of the National Heavy Vehicle Safety Initiative funded this report to further investigate the handling implications of safety chain fitment on larger combinations. As such, this project includes in-field dynamic on-road testing of two larger combinations:

- Rigid truck towing a 5-axle dog trailer
- Rigid truck towing a 6-axle dog trailer.

Project Objectives

The objectives of this phase of the test program are to build upon previous work completed, by examining the following factors:

- Determine whether the combination be safely stopped in the event of a trailer separation incident.
- Examine the stability of the combination in a range of scenarios covering speed, load, configuration, turning, acceleration and deceleration.
- Better understand what scenarios are most critical for vehicle stability in the event of safety chains fitted during a trailer separation incident.
- Examine the geometric implications of the fitment of safety chains and their attachments in relation to the proximal components on the truck and trailer.

As the Australian fleet of high productivity vehicle combinations increases in quantity, mass, and exposure to higher density populations, the risk profile increases. Within this context the use of safety chains to provide a redundant load path in the event of sudden trailer disconnection may have a role to manage the risk profile in line with acceptable community expectation.

This project provides both an evidentiary basis for the consideration of safety chains as a risk reduction measure and provides some recommendations regarding the effective installation the necessary components for this application. These findings and recommendations can inform the development of future regulatory guidance regarding the use of safety chains.

2. Methodology

Before the use of safety chains on heavy vehicle combinations in Australia can be considered, there is a need for an evidentiary basis in order ensure confidence within industry and the community. The test program is designed to address concerns regarding the safety of a combination operating only with the use to safety chains. Key considerations are:

- The strength of the safety chains and their connections.
- Dynamic effects including any sudden loading or backlash.
- Stability of the combination when operational and connected with only chains.
- The retention of effective control lines - air and electrical systems for braking and lighting.

In addition, the retro fitment of the necessary safety chain components had the benefit of contributing to observations regarding best practice fitment, taking into account:

- Recommendations for component location and fitment proximal to coupling points
- Location and strength of substrate material to which chain attachments are welded
- Fitment in relation to service lines
- The requirement for crossed chains
- Chain length recommendations
- Usage factors including ergonomics.

2.1 Previous research

This project is intended to build upon previous research completed by Advantia on the effects of safety chains for a rigid truck and 4-axle dog[1]. As such, the methodology for this project has been drawn from the previous methodology, similarly seeking to subject high productivity vehicle combinations to real-world laden and unladen testing in many operational scenarios while being connected only using safety chains.

The primary purpose of the methodology used is to achieve quantifiable measures of vehicle safety and stability, with measurement completed using a number of measurement devices including accelerometers and cameras. Data acquisition included relative acceleration, velocity and location information which were then analysed and compared to understand the effects of the safety chains. Importantly, human factors were also considered, and in all scenarios in-field observations and driver interviews were also conducted.

The test chronology and methodology were also designed to ensure safe undertaking of the testing, with test scenarios taking place at gradually increasing levels of speed and energy as each benchmark set of tests were completed - ranging from walking pace up to highway speeds.

2.2 Test vehicles and driver set up

This research program utilised two combinations to continue from previous research completed by Advantia. Previously a truck and 4-axle dog trailer were used while this testing program utilised a truck towing a 5 and 6-axle dog trailer combination. The same truck was used in both combinations with different trailers.

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[1] https://www.advantia.com.au/wp-content/uploads/2018/08/2547-03.pdf

Truck & 5-axle dog

Figure 1 shows a layout drawing of the truck and 5-axle dog trailer combination used in the testing program. Additional specifications and PBS performance results for the combination is included in Appendix A. The truck was tested at both maximum axle loads (63.0 tonnes) and in the unladen case (approximately 18.8 tonnes). The combination includes EBS brakes but no advanced safety features (e.g. Trailer Roll Stability programs).

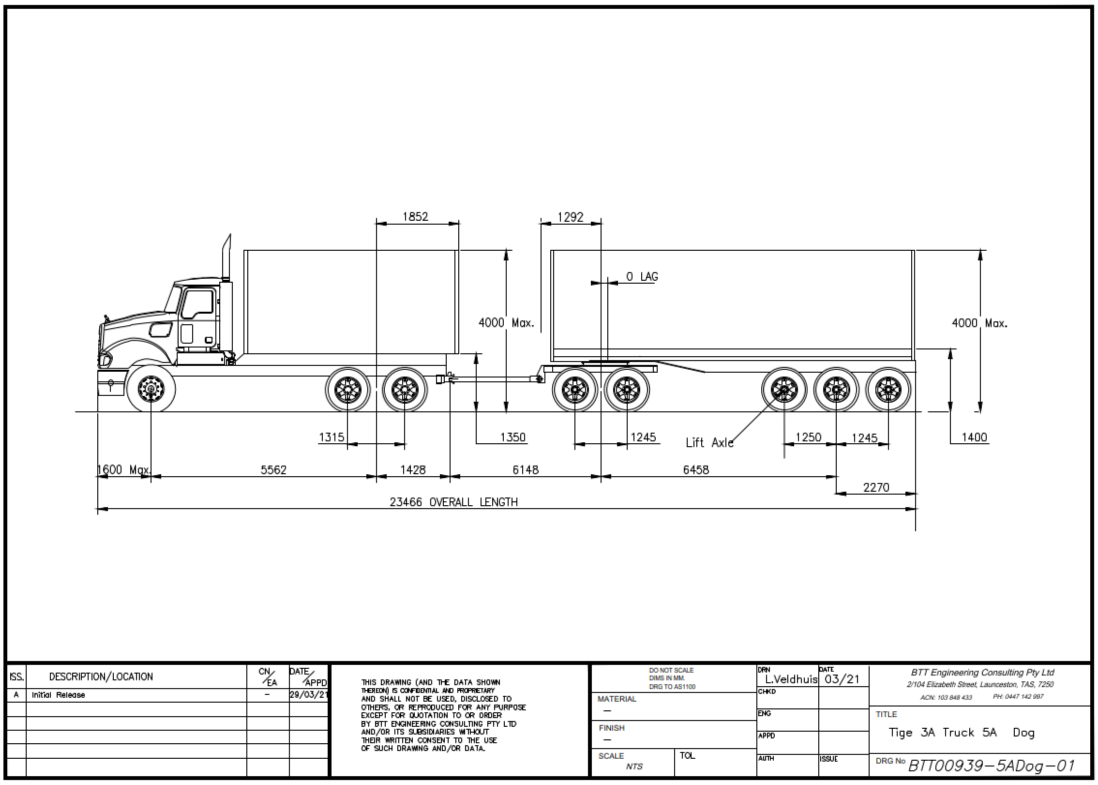

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Figure 1 – Truck & 5-axle dog layout drawing

Truck & 6-axle dog

Figure 2 shows the layout drawing of the truck and 6-axle dog trailer combination used in the testing program. Additional specifications and PBS performance results for the combination is included in Appendix A. The truck was tested at both maximum axle loads (68.5 tonnes) and in the unladen case (approximately 19.8 tonnes). The combination includes EBS brakes but no advanced safety features (e.g. Trailer Roll Stability programs).

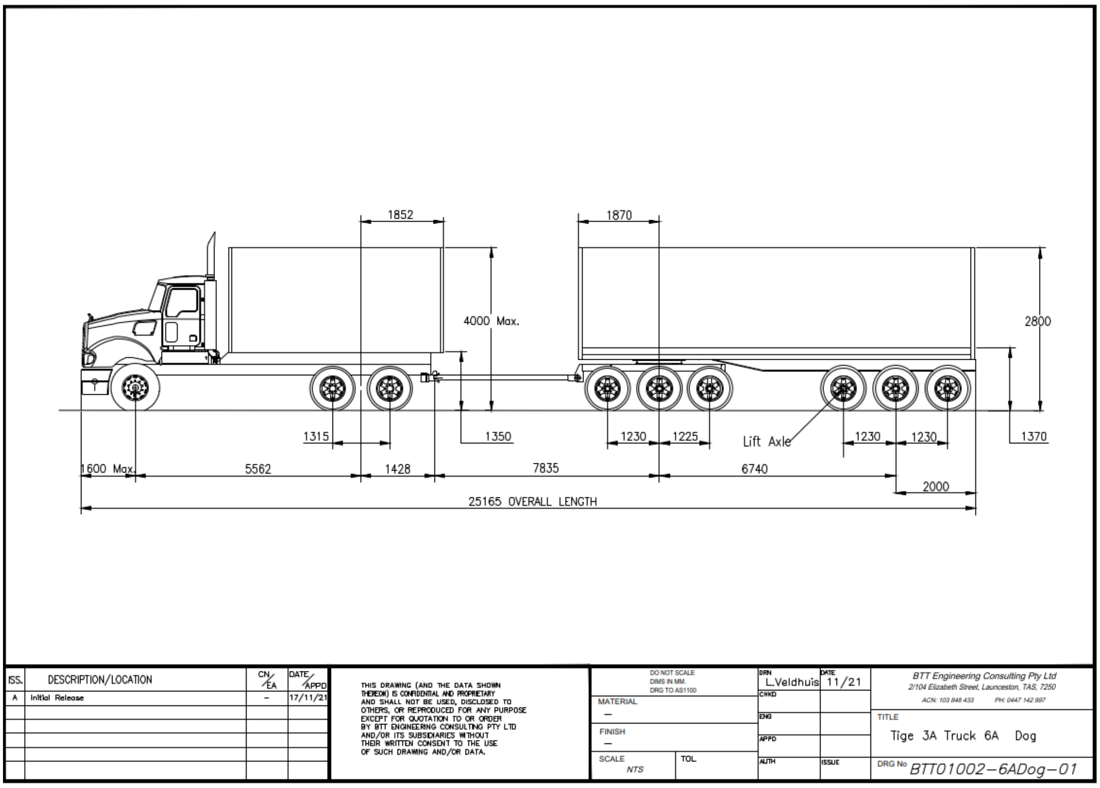

Figure 2 – Truck & 6-axle dog layout drawing

Safety chains

The safety chains and attachments were fitted in line with Australian Design Rule ADR62/02 requirements. This Design Rule requires that the safety chain is attached as close as practicable to the coupling points. The means of chain attachment on both the truck and trailer was using ADR rated Bartlett safety chain attachments, part number BK20, CRN Number 49482.

Truck side

The truck towbar was fitted with safety chain attachments either side of the coupling on an available rearward facing face of the existing towbar. In this case, the retro fitment of the safety chain attachments involved first fitting a 20mm spacer plate to enable the safety chain attachment to be located either side of the coupling, without interfering with an outer rim feature of the existing towbar. This allows the safety chain attachments to be fitted to the preferred location as close as practicable to the coupling point. The fitment is shown in Figure 3.

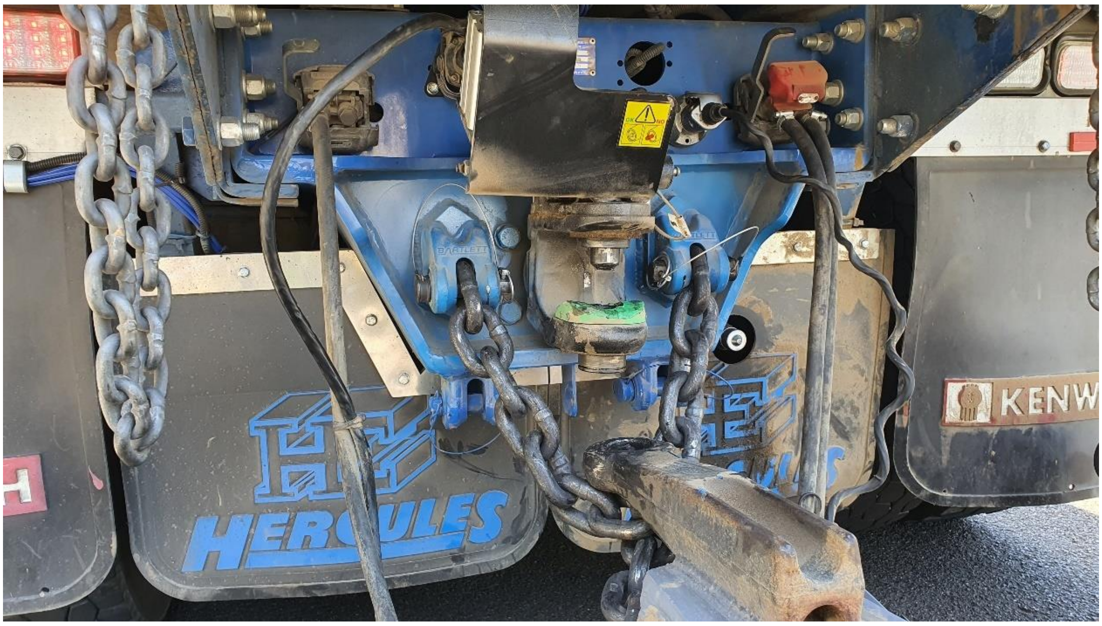

Figure 3 – Truck safety chain attachment and location

Trailer side

Both the 5-axle and 6-axle trailers required the retro fitment of safety chain attachments to a location near the trailer coupling point. This location is as shown in Figure 4.

The safety chain attachments must be fitted to a structurally significant substrate element, which must also be capable of passing ADR62/02 design forces for safety chain attachments. This strength was achieved by fitting a supporting plate to the outer lower side of the trailer drawbar. This strengthening substrate component was 8mm thick and extended from the forward-most location of the drawbar to approximately 800mm rearward, with a generous taper to the centreline of the drawbar in order to avoid local stress raisers.

Figure 4 – Trailer safety chain fitment on trailer drawbar

Truck cabin automatic pin controls

A V.Orlandi E550 automatic pin coupling with pneumatic remote operation was selected for its ability to be adapted such that the coupling could be remotely disconnected from the cabin of the truck in order to facilitate testing of the disconnection of the trailer while underway.

The system design for the disconnection of the automatic pin while underway included multiple redundant systems to ensure a safe connection when operating outside of the test program.

2.3 Test facility

All field testing was completed at the Australian Automotive Research Centre (AARC). The AARC is a privately owned proving ground which includes a range of testing roads and areas for automotive field testing. The site is located near Anglesea, Victoria. An aerial view of the AARC site is included in Figure 5.

Figure 5 – AARC facilities (Source: AARC)

By completing the testing in a secured and off-road location, the risk profile of the project was reduced. Advantia implemented a risk reduction process in-line with industry best-practice for managing risks involved with fieldwork.

In the case of this project, the major safety risk was rollover or loss-of-control of the heavy vehicle combination. As such, exclusive use of the highway circuit was arranged. The only vehicles operating on the circuit was the heavy vehicle combination and the chase car at a safe stopping distance. All field testing of the combination was completed on the highway circuit including driving the vehicle at walking speed to make initial observations. The highway circuit is also fully fenced so chance of wildlife entering during the testing was minimised.

The highway circuit was chosen for both this project and the previous research as the best available facility at the AARC. The circuit's surface texture, roughness profile and geometry are similar to typical Australian roads.

The circuit itself is 4.2 km 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. Travel on the highway circuit is in an anti-clockwise direction. The circuit also included a parking area where adjustments to the testing equipment and observations of the stationary vehicle were made. Figure 6 shows the test vehicle on the highway circuit at AARC.

Figure 6 – The test vehicle on the highway circuit

2.4 Experimental testing manoeuvres

The objective of the field tests was to collect data to enable the dynamic stability of the truck and trailer combination with various coupling and load configurations to be quantified.

Determination of safe speeds

During the first portion of each day, the coupling was disengaged (chains only), and starting from walking pace, the driver increased the speed of the vehicle by 5 km/h increments until reaching the final safe speed. The driver started by travelling in a straight line and negotiating the bends, and ultimately moving to swerving/slalom type manoeuvres. The maximum safe speed was 80 km/h for all tests, except for the swerving/slalom type manoeuvres, where the maximum speed was 60 km/h.

During this section of the testing, only camera footage was captured, but no data was logged.

Overview of field tests

A total of six different types of tests were conducted, where data was logged. These are in addition to the informal 'observations' made of vehicle performance at low speed. The tests were:

- straight line travel (coupled and chains only)
- controlled braking (coupled and chains only)
- pulling over and stopping (coupled and chains only)
- negotiating curves (coupled and chains only)
- swerving at constant speed (coupled and chains only)
- disengaging coupling while travelling in a straight-line constant speed
- disengaging coupling while cornering at constant speed.

Straight line travel

The straight-line travel test was conducted on the straight segments of the track, where the driver attempted to hold a straight line. These tests were conducted at 40, 60, and 80 km/h.

Controlled breaking

The controlled breaking test was conducted on the straight segments of the track, where the driver attempted to hold a straight line and then apply the brakes until stationary. These tests were conducted at 40, 60, and 80 km/h.

Negotiating curves

Negotiating curves tests were occur as the vehicles rounds the two bends on the test course. The driver attempted to keep the turn steady (i.e. constant radius and lateral acceleration). These tests were conducted at 40, 60, and 80 km/h.

Slalom course

The 'slalom course' comprised a series of gates (created using two cones) positioned on the roadway (straight section) according to the layout shown Figure 7. These were only conducted at one speed (60 km/h).

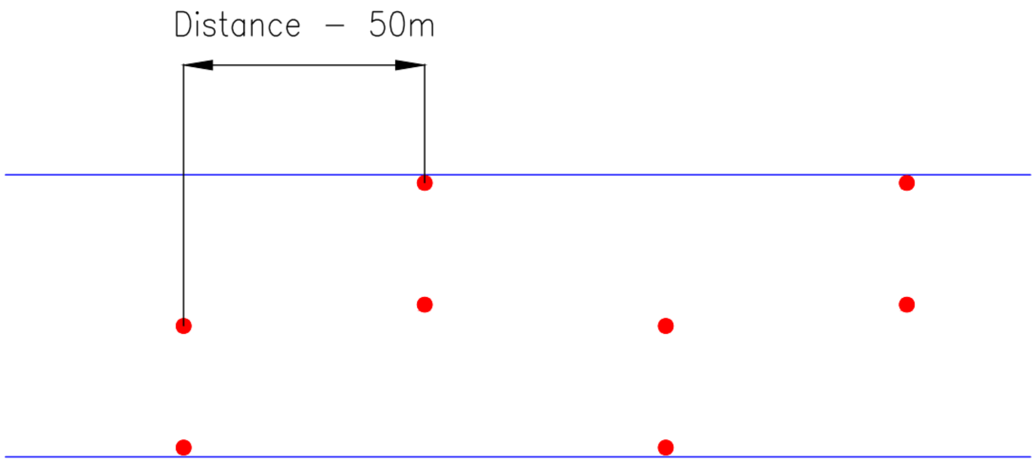

Figure 7 – Overview of the slalom set up (not to scale)

Pulling over and stopping

This test involved the vehicle travelling at a constant speed, and the application of the brakes and simultaneous steering input, intended to simulate an emergency ‘pull-over and stop’ manoeuvre. The intention was that the driver simulates a ‘lane change’ manoeuvre, but instead of the speed remaining constant, the brakes were applied as the manoeuvre was being undertaken.

Field test matrix

For each of the tests, the matrix of load and coupling configurations that was conducted for the varying speeds are shown

Table 1.

Table 1 – Field testing matrix

Tests	Unladen		Laden	
	Coupled (baseline)	Un-coupled (chains)	Coupled (baseline)	Un-coupled (chains)
Straight-line travel (km/h)	40, 60, 80	40, 60, 80	40, 60, 80	40, 60, 80
Straight-line braking (km/h)	40, 60, 80	40, 60, 80	40, 60, 80	40, 60, 80
'Pulling-over' and braking (km/h)	40, 60, 80	40, 60, 80	40, 60, 80	40, 60, 80
Negotiating curves (km/h)	40, 60, 80	40, 60, 80	40, 60, 80	40, 60, 80
Slalom/swerving (km/h)	40, 60	40, 60	40, 60	40, 60
Disengaging coupling – straight line at constant speed (km/h)	40, 60, 80		40, 60, 80	
Disengaging coupling – cornering at constant speed (km/h)	60 (Corner 1) 60 (Corner 4)		60 (Corner 1) 60 (Corner 4)	

NOTE: Tests were conducted with ascending speed up to the maximum speed considered safe for the field tests.

Test area layout

The areas where the tests were conducted are shown on the diagram of the highway circuit in Figure 8 – Test area layout

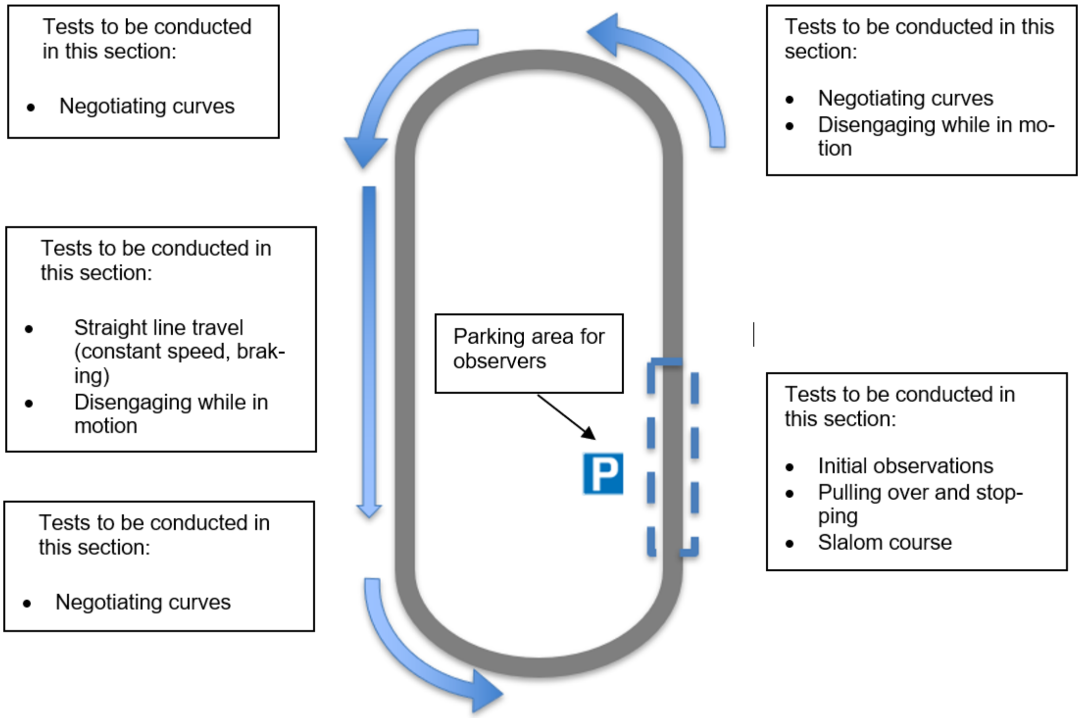

Figure 8 – Test area layout

2.5 Data logging and field test equipment

The test vehicle was fitted with Advantia's heavy vehicle data acquisition system. The system comprises a computer-controlled, centralised data logger that records data from various sensor boxes that are fitted to test vehicles.

The system uses commercially available 'MoTeC' brand components that are typically used in professional motorsport applications, and Bosch sensors, both adapted into a custom-built system to suit Advantia's requirements for heavy vehicle field tests. The system continuously recorded the following data during the tests:

- speed and position (i.e. latitude and longitude)
- lateral, longitudinal and vertical acceleration
- yaw rate.

In order to capture this data Advantia utilised a field test system largely comprising of three modules:

- Master box module – data logger connected to laptop and GPS receiver
- Slave module 1 – captures truck yaw rate, roll rate, tri-axial acceleration
- Slave module 2 – captures trailer yaw rate, roll rate, and tri-axial acceleration.

These are shown on one of the combinations in Figure 9 with the master module shown in blue, the slave module 1 in red and the slave module 2 in green.

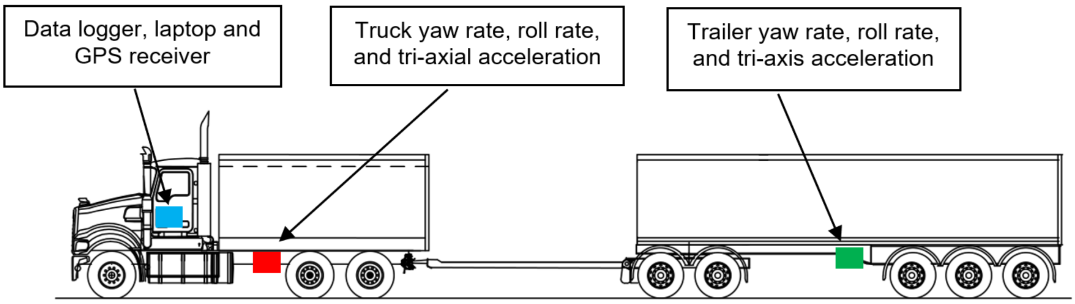

Figure 9 – Layout of testing equipment on the combinations

The master box is positioned inside the cabin, on the floor of the vehicle, between the drive and passenger seats. The two slave boxes are positioned underneath the tipper body, on either the left or right-side chassis rails, as near to the centroid of the unit as possible. These were attached rigidly to the vehicle and orientated so that they could capture lateral, longitudinal and vertical acceleration of the units.

The coordinate system used is shown in Figure 10.

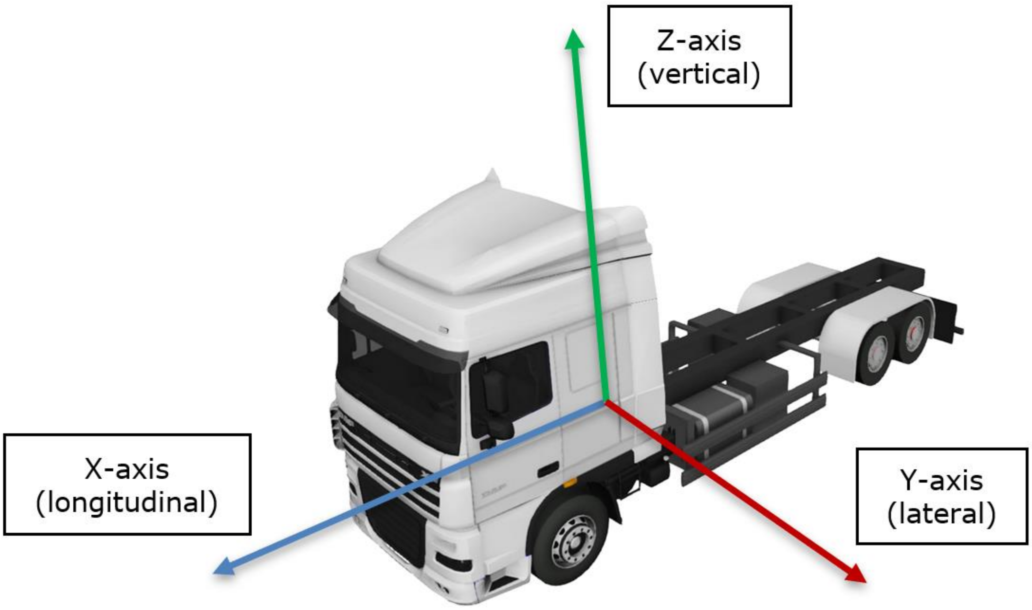

Figure 10 – Three-dimensional coordinate reference system

The 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 selected. Table 3 shows the sampling rate, measurement range, and resolution of the system's sensors.

2.6 Data analysis

The data was exported from the data collection system/Motec into a CSV format and processed in Microsoft Excel with a focus on three main parameters:

- Lateral acceleration
- Longitudinal acceleration
- Yaw rate.

While the sensor data provided valuable information, the first step to retrieve meaningful results was to clean the data and reduce the amount of noise present. A range of frequency filters were applied depending on the case as the levels of noise varied significantly across different speeds, load cases and dog trailer configurations. Figure 11 shows the same data set before any processing (orange) and after being filtered with a 5 Hz filter. The 5 Hz filter allows the trend to be understood by reducing the significant high-frequency noise in the data.

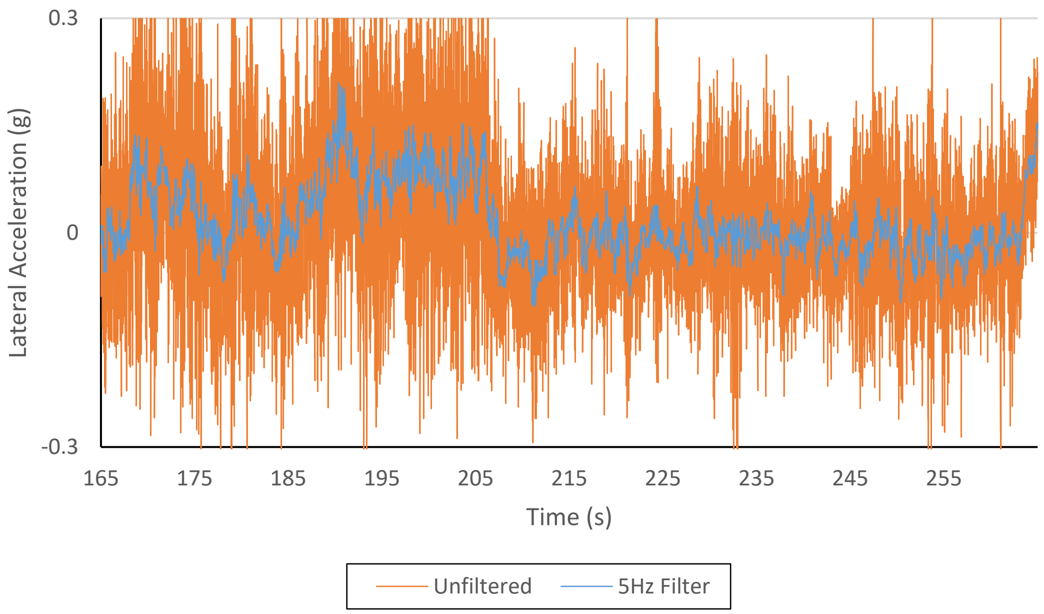

Figure 11 – Example pre- and post-processed data

The filtered data was then analysed using three main methods:

- Plotting the parameter as it varies against time
- Plotting the Probability Density Function (PDF) for the given parameter
- Calculating the Root Mean Square (RMS) and peak values for the parameter.

Plotting the parameter as it varies against time is useful for visually identifying the behaviour of the unit or directly comparing two tests against each other to observe any differences in behaviour. This is the most intuitive analysis method and is best as a starting point to give understanding of what is occurring during the test.

For a more precise analysis the PDF can be used to represent how often different magnitudes of the parameter occur for each scenario. Using the PDF allows to see what magnitudes are common during a manoeuvre. This can highlight small differences between scenarios by overlaying the PDF curves and comparing their shapes. This may show differences that could not be easily observed in the time trace alone.

Finally, the RMS and peak values can be used to provide an idea of the average and peak magnitude of the parameter of interest. This can give a precise numerical representation of the different behaviour of scenarios. This method is most susceptible to natural variation, outliers or differences in vehicle path and speed.

The driver was also interviewed during the testing to capture their experiences of controlling the vehicle during the test and provide any feedback about the behaviour of the combination. The driver was asked about their ability to control the combination, any feedback they are receiving from the handling of the combination and their thoughts on the overall behaviour of the combination.

3. Results and discussion

3.1 General observations of vehicle behaviour

This section covers off qualitative observations around the performance of the combination when utilising safety chains based on driver and chase car experiences.

Tests conducted at walking pace

To maximise the safety of the field testing undertaken, the first series of tests for each of the loading conditions and combinations included an informal set of manoeuvres designed to confirm understanding of the kinematics of the coupling with safety chains and whether any immediate issues might arise. In these tests the drawbar tow-eye was disconnected from the hauling unit and supported only by the installed safety chains. Examples of issues that may have arisen include:

- Insufficient clearance of the drawbar to the ground
- Pinching or crushing of the air and fluid lines
- Mechanical/electrical failures of the de-coupling mechanism.

The tests involved the driver driving forward initially at walking speed and then performing a gentle braking maneouver. This was followed by the driver performing a gentle slalom manoeuvre.

In the initial series of tests the combination was fitted with safety chains as per the manufacturer’s advice, with the chains crossed and supporting the tow-eye on the drawbar. Due to the lengths of the chain links, the amount of slack in the chains allowed a limited degree of freedom of the tow-eye and the tow-eye sat on the lip of the funnel of the coupling fitted to the truck. This can be seen in Figure 12 which shows the drawbar tow-eye when connected only by the safety chains and Figure 13 when normally connected to the tow coupling. When the chains were slack the tow-eye was guided by the funnel of the coupling to sit within the tow-coupling housing, similar to where it sits during normal operation.

For the testing program the length of chains used was also briefly investigates however it was identified that if additional chain links were used the drawbar would likely make contact with the road surface. As a result this was not pursued. Operation of the drawbar outside the coupling funnel was investigated however, and this has been described later in this section.

Figure 12 – Decoupled trailer connected with safety chains

Figure 13 – Coupled trailer connection

As a result of this set up, the movement of the tow-eye with respect to the tow-coupling on the truck was highly constrained. As such, during these tests, similar tracking performance was observed between the combination connected with only safety chains and the combination coupled via the tow-coupling. The main observable difference was longitudinal shunting of the combination which could be felt in the cab and be heard from the chase car.

Figure 14 shows a close view of the coupling funnel and the resting point of the tow bar eye when the chains were taught. There is also a distinctive wear pattern which can be seen on the coupling funnel showing the range of motion of the tow bar eye within the coupling funnel during the testing.

Figure 14 – close view of the coupling funnel

Driver feedback echoed the observed results in that it was felt that the trailer had no stability or control issues and that it was not obvious when the trailer was uncoupled. When asked about their opinion on the severity of the shunting the driver did not indicate concern for the vehicle or the stability of the combination.

In recognition that the constrained movement was a result of the end of the drawbar sitting on the chains and lip of the coupling funnel and that a common failure point involved the welds between the tow-eye and the drawbar pull, additional tests were also undertaken without the funnel present. This was done to simulate the end of the drawbar or the tow-coupling funnel breaking as part of the trailer separation event. The modifications were made to the tow-coupling to test this configuration with the unladen six-axle dog trailer configuration.

Under this configuration the tow-eye had significantly more travel distance afforded to it which was of interest in the project. An image of the drawbar hanging in the neutral position is shown Figure 15.

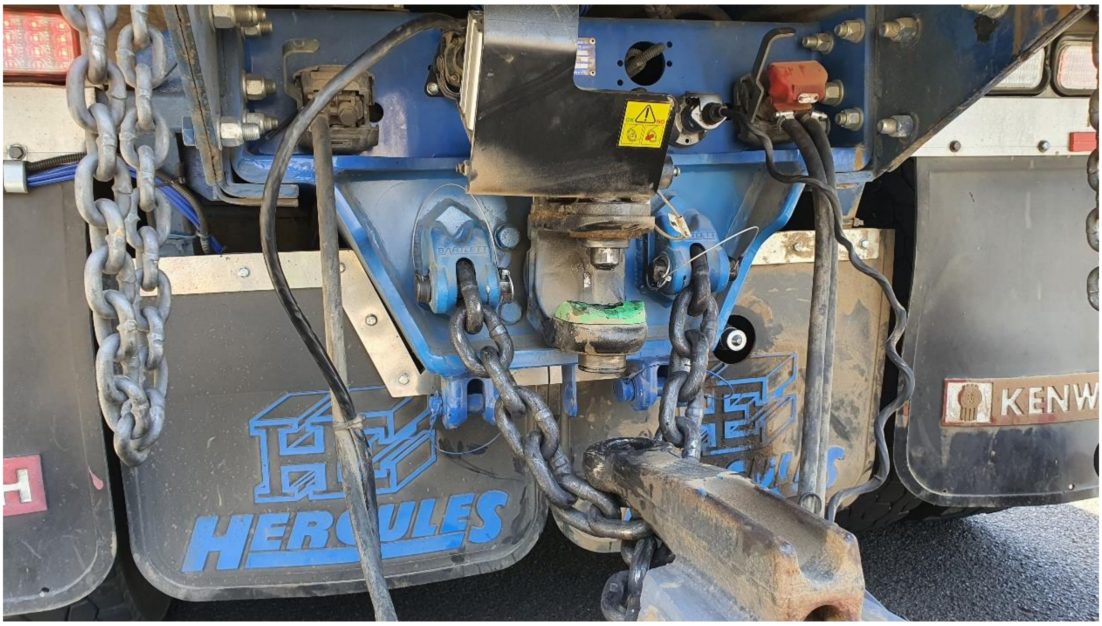

Figure 15 - Drawbar held by chains without coupling funnel

Even with this increased travel of the tow-eye there were no discernible differences in tracking between this configuration and other configurations at walking pace. The only major difference was that the audible sounds of impact between the tow-eye and the truck were much louder.

When interviewing the driver about their experiences with this configuration the driver noted that they could feel a significant difference between when the tow-eye was constrained within the coupling funnel and when it was not. This was mostly in relation to the shunting as the severity of the impact was increased and much more obvious. The driver and passenger likened it to being rear-ended by a passenger car. The driver and on-site mechanic made a second inspection of the coupling housing as the driver felt that it was severe enough that damage to the truck may have occurred. No damage was noted.

Based on the results of these tests it was considered safe to move onto testing at 40 km/h.

Tests conducted at 40 km/h

When testing at 40 km/h the trailer's on-road performance was similar in all configurations tested.

From the perspective of the chase car it was not discernible whether the trailer was wandering more significantly or not, even when the coupling funnel was removed, including decoupling at speed. Review of the footage of the coupling showed that while uncoupled (with the funnel present) the safety chains were mostly in tension or in the neutral position resting on the coupling funnel. Figure 16 shows the drawbar in the neutral position resting on the lip of the coupling funnel. The trailer would also intermittently push and pull on the truck and this was identified by the driver as the key indicator that the trailer was even decoupled.

Figure 16 – Tow-eye coupling in neutral position

It was only during the slalom maneouver that the tow-eye experienced notable lateral movement. In these cases however the tow-eye was still constrained by the coupling funnel restricting its motion to an approximate 200 mm range of motion. Figure 17 shows the approximate range of motion of the drawbar eye in the coupling funnel.

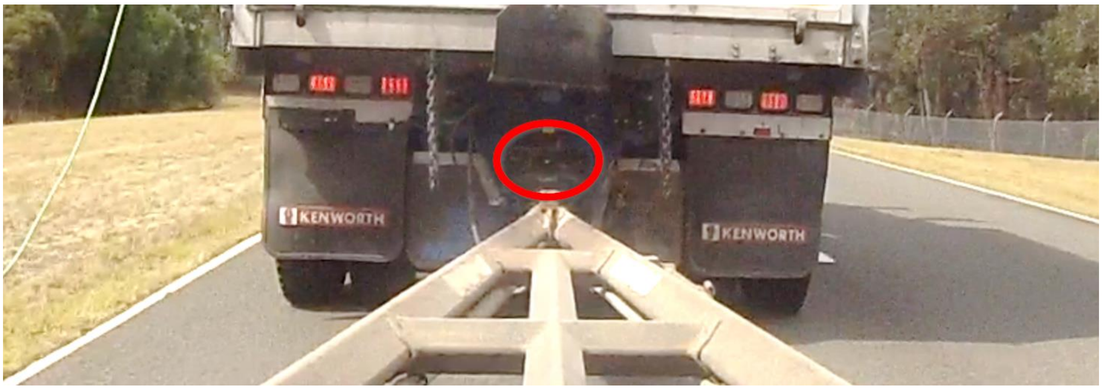

Figure 17 – Tow-eye coupling range of motion

These observations from the chase car and footage were echoed by the driver who noted that they did not have any concerns around controlling the trailer. The only major differences between the laden and unladen vehicles being the feel of the shunting and pulling caused by the safety chains. The driver described the unladen trailer having a "snappier" and more sudden while the laden trailer was more dulled in comparison. During the slalom and pull over and stop they didn't feel a difference between the laden and unladen tests or between the 5 and 6-axle dog trailers.

During the braking from speed tests the driver did not identify any handling issues which would affect the safety of the combination. On application of the brakes the driver could was initially surprised at how smooth the braking was with the trailer uncoupled. Like other tests the main experience noted by the driver was pushing and pulling from the trailer. The driver noted that it was the pushing and pulling was more violent in the laden case but still manageable with no concerns raised.

When the coupling funnel was removed, the tow-eye was able to wander more however this additional freedom appeared to have little impact on the tracking of the trailer. During the slalom maneouver and the turns were the only times at which significant lateral movement of the tow-eye was observed. The rest of the time, the tow-eye largely remained under tension centred on the tow-eye. Figure 18 shows the maximum left and right positions of the tow-eye drawbar before the chains limited further lateral movements.

Figure 18 – Maximum lateral travel of the tow-eye with no coupling funnel relative to the coupling

During testing with the coupling funnel removed, the only major observable difference between this and other tests was that the drawbar moved relatively violently when the combination braked. It appeared that the trailer braking harder than the truck caused sudden tensioning on the chains resulting in the end of the drawbar being raised slightly above the coupling briefly as it followed the arc allowed by the safety chains before quickly falling back down. The driver described this as the trailer aggressively hitting the truck although only the trailer pulling back on the truck was observed.

For the test which included decoupling while in motion, at either turn 1 or turn 4 of the circuit the driver did not identify any handling issues which could potentially cause a problem. It was noted by the driver that there was a slight jolt in the truck as the chains tensioned but this was largely not noticeable. From the perspective of the chase car the performance of the trailer did not differ before and after decupling at speed.

Tests conducted at 60 km/h and above

The results of the tests completed at 60 km/h and above were similar to the results observed at 40 km/h and below. This was not an unexpected finding as similar trends were also observed in prior research completed by Advantia.

The chase car observations showed that in both cases (uncoupled vs. only connected by safety chains) the trailer had more significant wandering at speed compared to when it was travelling slower. Again however, the differences in lateral wandering between configurations at the same speed was not significant.

During the slalom maneouver the lateral movement of the trailers were similar to that at 40 km/h; at all speeds the safety chains were constraining the movement of the drawbar (even without the coupling funnel) to remaining close to the centre of the truck.

In the de-coupling while in motion tests, the performance from the chase car was similar (no significant differences). However, the driver noted that in all cases they could feel when the chains became taught as they “caught” the trailer. At higher speeds however the momentum of the trailer was such that it took longer to feel this tensioning point. At 40 km/h this delay was approximately 4 seconds while at higher speeds the delay increased to approximately 8 or 10 seconds. This however did not impact their ability to handle the trailer.

The main difference that was observed at higher speeds only occurred with the coupling funnel removed. With the funnel removed, the frequency and intensity of the shunting and pulling on the safety chains and truck increased dramatically with speed. While this did not have an effect on the lateral handling it made it much more obvious to the driver that the trailer was de-coupled.

Based on the severity of the impacts on the truck and trailer and the negligible differences in observed handling of the trailers only testing with the unladen six-axle dog was completed with the funnel removed.

Summary of findings from general observations

The general observations made during the field testing were valuable in understanding the general performance of the safety chains and the overall behaviour of the truck and trailer.

Specifically it was found that when the coupling was disconnected, and the trailers were only held by the safety chains:

- The drawbar eye was constrained in its range of movement by the safety chains and if present the coupling funnel
- The trailer could push and pull on the trailer as well as sway from left to right
- The pushing and pulling were noticeable by the driver but largely unnoticeable to the chase car observers
- Allowing the drawbar eye more freedom of movement resulted in increased shunting and pulling but did not cause noticeable changes in the lateral sway or handling of the trailer
- The shunting and left/right movement of the drawbar did not affect the handling of the trailer and the driver's ability to control the combination
- The driver was able to perform evasive manoeuvering of the combination safely without requiring increased effort to control the combination.

3.2 Data analysis

The disconnection of the drawbar coupling was shown to have little effect on the stability or overall dynamic behaviour of both combinations in both the laden and unladen cases.

The results presented through this section aim to quantify the changes in behaviour. Not all speeds and cases have been presented as the behaviour between laden and unladen, 5-axle and 6-axle and different speeds is shown to be consistent demonstrated by specific examples.

For clarity, where a chart shows a comparison between two configurations (e.g. coupled vs uncoupled) only results for the trailers have been shown.

Effect of payload

The combinations were tested in both the laden and unladen cases to understand the differences in behaviour between the loading cases. General trends showed that overall performance was similar however some differences were observed.

Figure 19 shows the PDF of a trailer under different loading conditions for both lateral acceleration and yaw rate. The lateral acceleration of the laden and unladen cases exhibit similar distributions, which is expected, as they follow the same path at the same speed (lateral acceleration is independent of mass). The unladen case shows higher occurrences of positive lateral acceleration values and conversely the laden case shows higher occurrences of negative lateral acceleration values. These differences are minor and are likely due to differences in path, speed and the effect of the superelevation of the circuit.

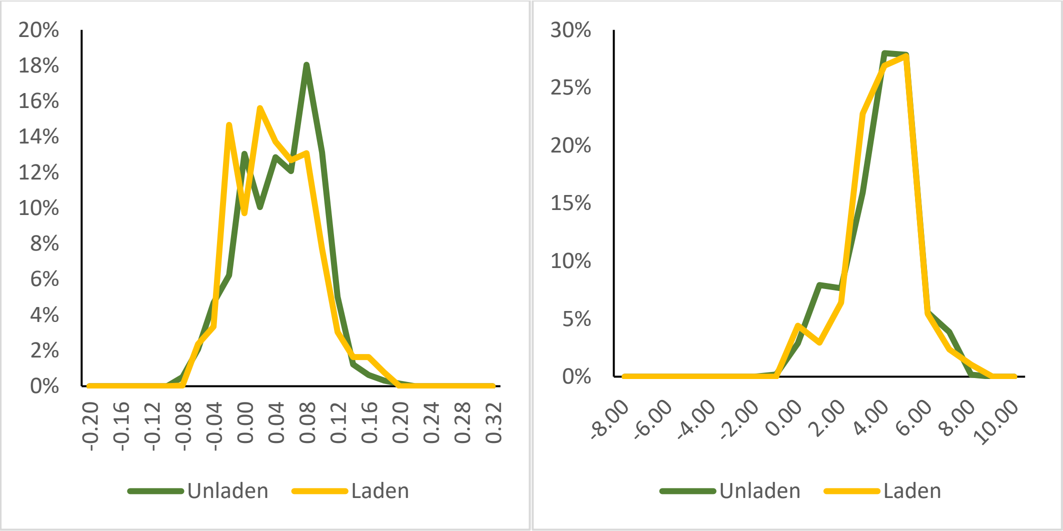

Figure 19 – PDFs of Lateral acceleration (left) and yaw rate (right) of unladen 5-axle dog at 80 km/h on turn 1 & 2

Figure 20 reinforced this finding by comparing the lateral acceleration paths directly. It can be seen both paths have minor differences but are materially the same.

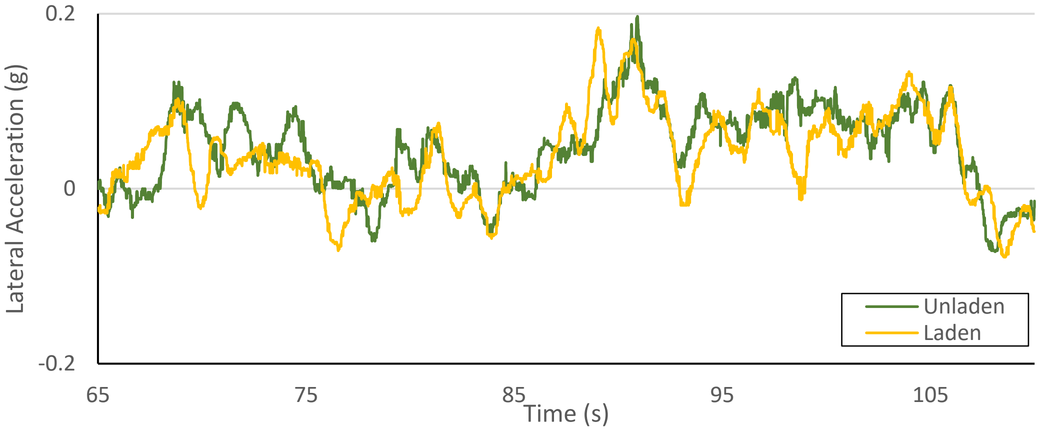

Figure 20 – Lateral acceleration of uncoupled 5-axle dog at 80 km/h on turn 1 & 2

Figure 21 also shows a similar finding with yaw-rate.

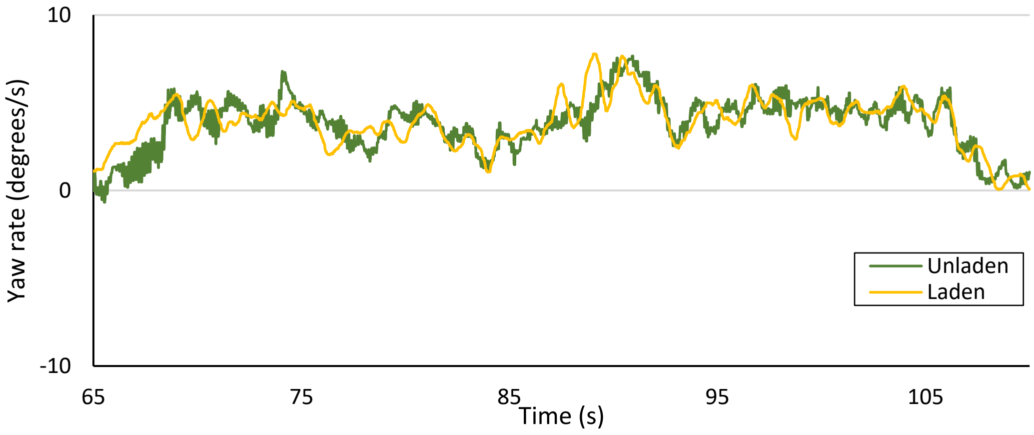

Figure 21 – Yaw rate of uncoupled 5-axle dog at 80 km/h on turn 1 & 2

In the case of longitudinal acceleration however, a more notable difference is noted between the two loading cases. This is demonstrated through the PDF shown in Figure 22.

The laden case experiences lower magnitudes of longitudinal acceleration and more frequent occurrences of longitudinal accelerations less than 0.02 g. This is likely due to the higher mass of the laden combination as it will be slower to accelerate and with its greater momentum it will be less affected by gradient changes that were present in the circuit.

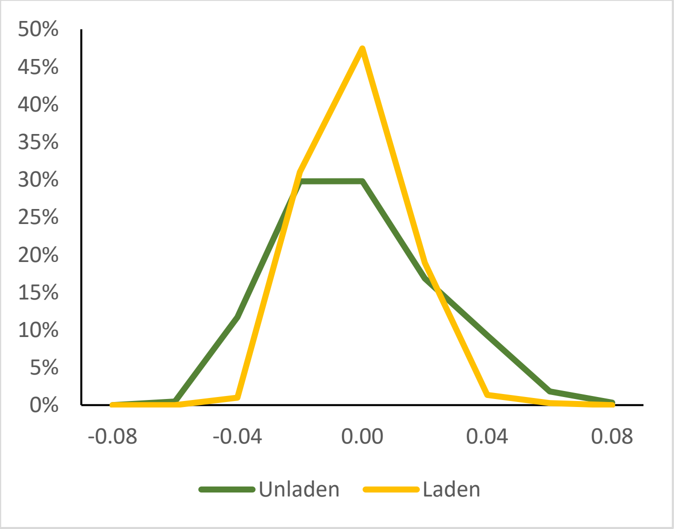

Figure 22 – PDF of Longitudinal acceleration of uncoupled 5-axle dog at 80 km/h on turn 1 & 2

Effect of trailer configuration

The 5-axle and 6-axle dog trailers show similar behaviour in their lateral acceleration and yaw rate. They show slight differences in their peaks and exact detailed values, however these differences can be likely attributed to differences in vehicle path and speed. The main observable difference in the yaw rate and lateral acceleration traces is the level of noise present for each combination, with the 5-axle combination showing a much higher level of noise even with the same 5Hz filter being applied to both combinations.

The level of noise in the signal is dependent on the vibration experienced by the sensors, as the two combinations have different suspensions, chassis structures and mounting of the sensors it is not unusual that they would experience different levels of vibration. However, the same frequency filter must be used when directly comparing the two sets of data as the filters will affect the magnitude of the data and will give an inaccurate comparison if different frequencies are used.

Figure 23 demonstrates how the same filter may not be appropriate for two different data sets as the 5-axle dog trailer with this filter contains more significant noise than the 6-axle dog trailer.

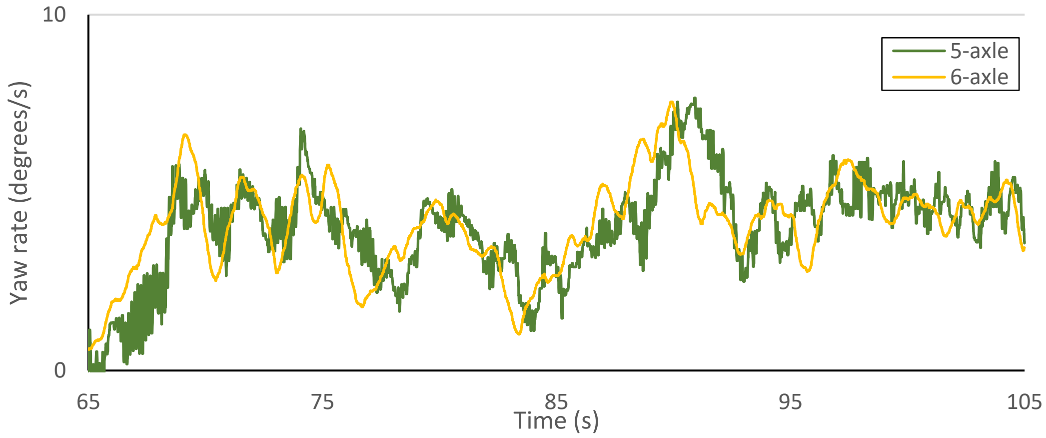

Figure 23 – Yaw rate of uncoupled unladen 5-axle dog and 6-axle dog at 80 km/h on turn 1 & 2

Figure 24 shows the PDF plots overlayed for the two combinations. The lateral acceleration PDFs are closely aligned, with the 6-axle distribution slightly offset towards negative values compared to the 5-axle. In the case of the yaw rate the 5-axle trailer shows a significant difference by having two peaks instead of a single peak. This suggests that throughout the turn the 5-axle dog trailer wandered back and forth while the 6-axle trailer maintained a constant yaw angle.

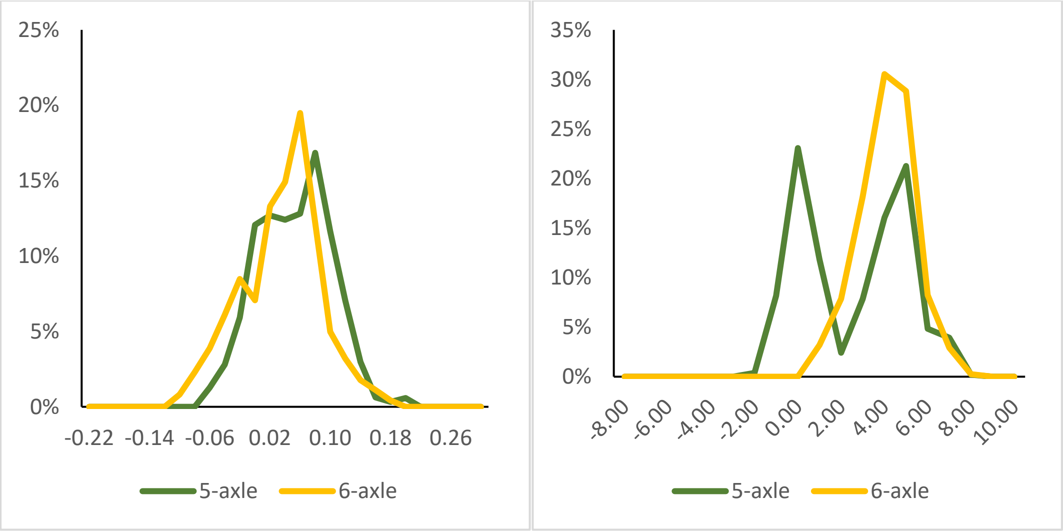

Figure 24 – PDFs of Lateral acceleration (left) and yaw rate (right) of uncoupled unladen 5-axle dog and 6-axle dog at 80 km/h on turn 1 & 2

In the case of the longitudinal acceleration, shown in Figure 25, the 5-axle shows greater variance in the acceleration values while the 6-axle dog trailer is more stable. The 6-axle trailer is more frequently experiencing little to no longitudinal acceleration. The 5-axle trailer also experienced a higher peak acceleration compared to the 6-axle (0.10 g vs. 0.06 g).

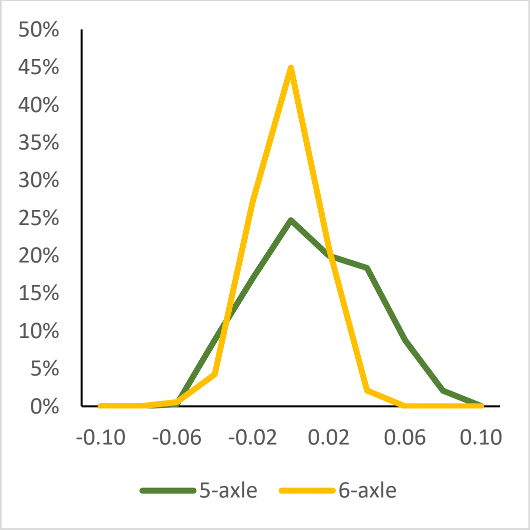

Figure 25 – PDF of longitudinal acceleration of uncoupled unladen 5-axle dog and 6-axle dog at 80 km/h on turn 1 & 2

Effect of test speed

The testing program included various speeds for the different manoeuvres to understand the effect of speed on performance. The test results found that for most parameters, the performance was similar at all speeds tested.

Figure 26 shows a comparison of the longitudinal acceleration of the combination at different speeds. The lower speed runs show higher frequency and amplitude of the longitudinal acceleration spike phenomenon.

Figure 26 - longitudinal acceleration on turn 1 & 2 at different speeds (uncoupled 5-axle dog trailer combination)

Figure 27 shows the yaw-rate of the trailer for turn 1 and 2 at different speeds. Both speeds show similar trends however the 80km/h has twice the yaw rate due to completing the turn in approximately half the time.

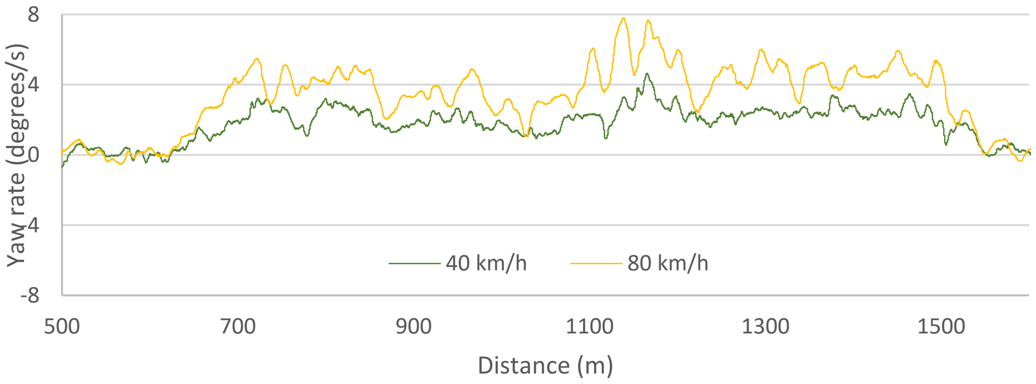

Figure 27 – Yaw rate on turn 1 & 2 (uncoupled 5-axle dog trailer combination)

Figure 28 show the lateral acceleration of the trailer as it completed turns 1 & 2 with approximately constant turning radii. Interestingly a significant difference is observed. Due to the camber in the road the 40 km/h data shows a negative lateral acceleration, however at 80 km/h the lateral acceleration from the cornering speed overcomes the lateral force from the camber angle and a net positive lateral acceleration is observed.

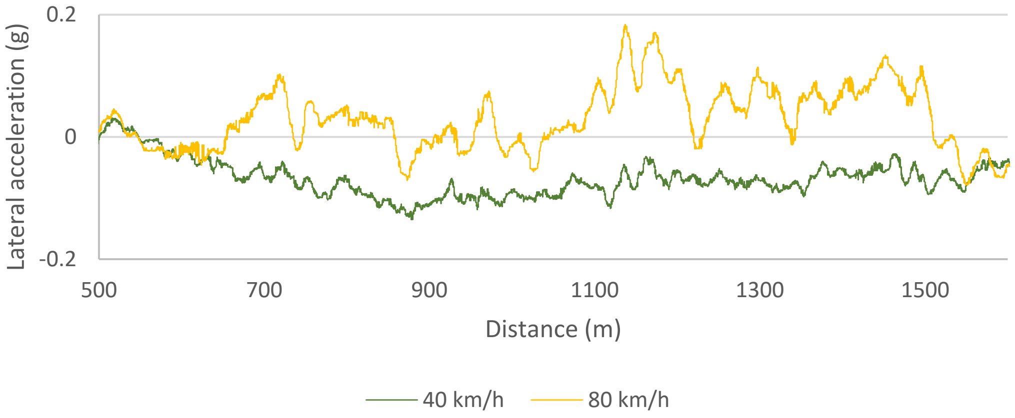

Figure 28 – Lateral acceleration on turn 1 & 2 (uncoupled 5-axle dog trailer combination)

For the comparison on straight sections of the circuit, Figure 29 and Figure 30 show the lateral acceleration and yaw rate respectively. In these cases the trends are similar, however the 80 km/h tests did show increased amplitudes in lateral acceleration, although overall lateral acceleration was negligible.

Figure 29 – Lateral acceleration on straight sections (uncoupled 5-axle dog trailer combination)

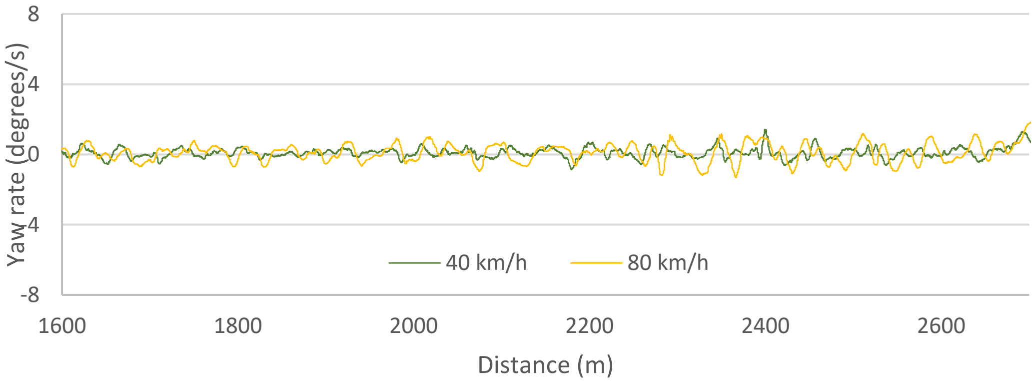

Figure 30 – Yaw rate on straight sections (uncoupled 5-axle dog trailer combination)

In the case of longitudinal acceleration, Figure 31 shows that the 40 km/h tests produced the highest spikes in longitudinal acceleration, and that in the 80 km/h tests the acceleration was comparatively smooth.

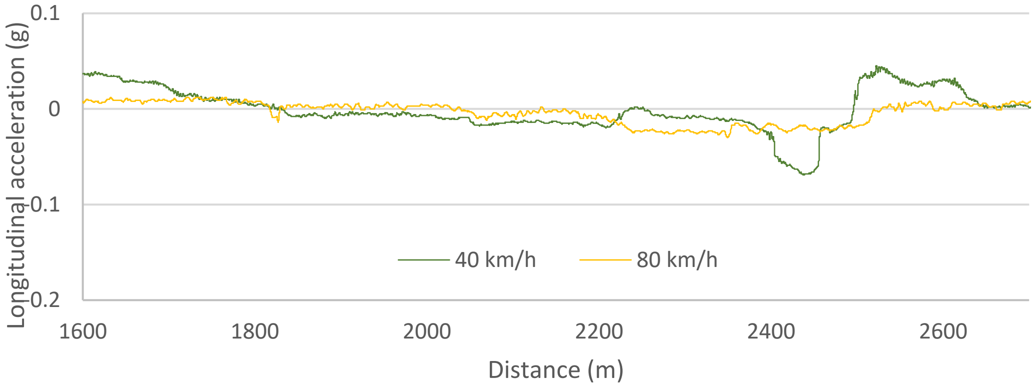

Figure 31 – Longitudinal acceleration on straight sections (uncoupled 5-axle dog trailer combination)

Based on these results, it shows there to be no significant differences in the trends when operating at different speeds, except for the case longitudinal acceleration where slower speeds produced worsened results.

Straight line travel at constant speed

During straight line travel the combination exhibited similar behaviour for both lateral acceleration and yaw rate when comparing coupled and un-coupled configurations. The most noticeable differences between the coupling states were seen in the longitudinal acceleration outputs wherein the pulling and pushing between the truck and trailer resulted in 'spikes' in longitudinal acceleration. However, these spikes quickly dissipated and did not translate in any way to yaw rate or lateral acceleration. Figure 32 shows these spikes as they occur during a run and that they quickly dissipate. In comparison, a baseline coupled combination does not exhibit these same spikes in longitudinal acceleration, shown in Figure 33.

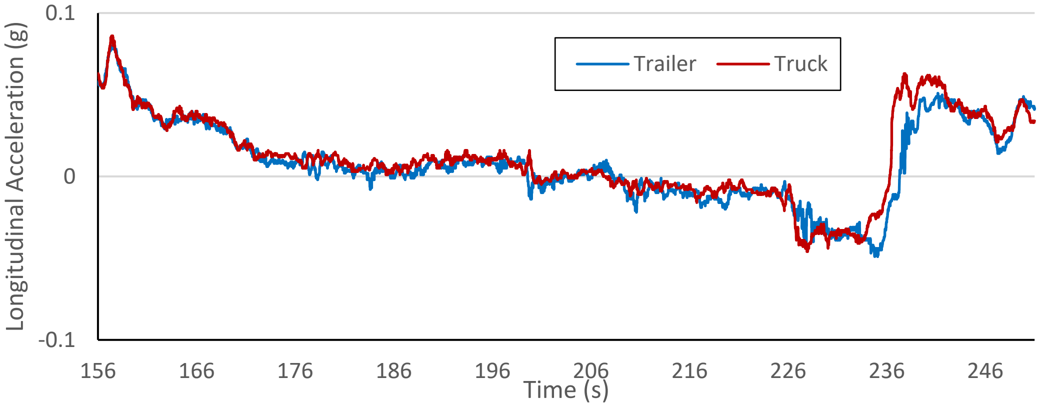

Figure 32 – Longitudinal acceleration for uncoupled unladen 5-axle dog at 40 km/h on straight section

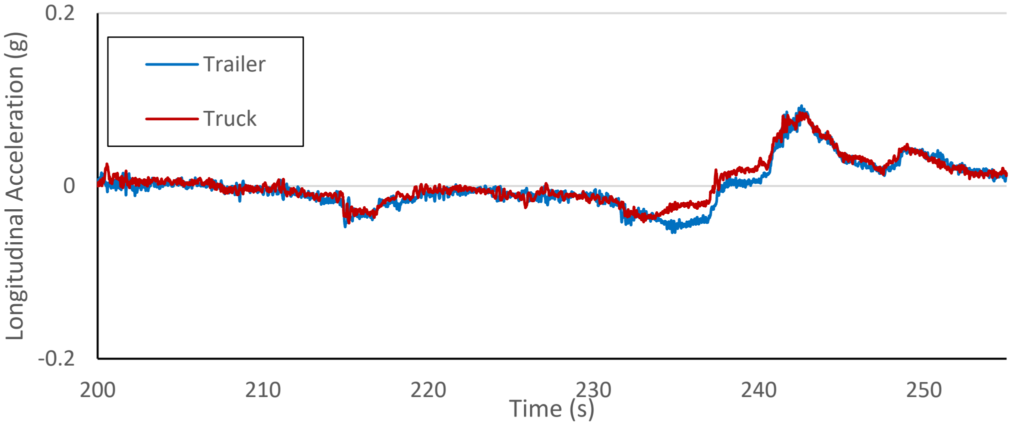

Figure 33 – Longitudinal acceleration for coupled unladen 5-axle dog at 40 km/h on straight section

In the cases of lateral acceleration and yaw rate however the results for both coupling cases are similar, as shown in Figure 34 and Figure 35.

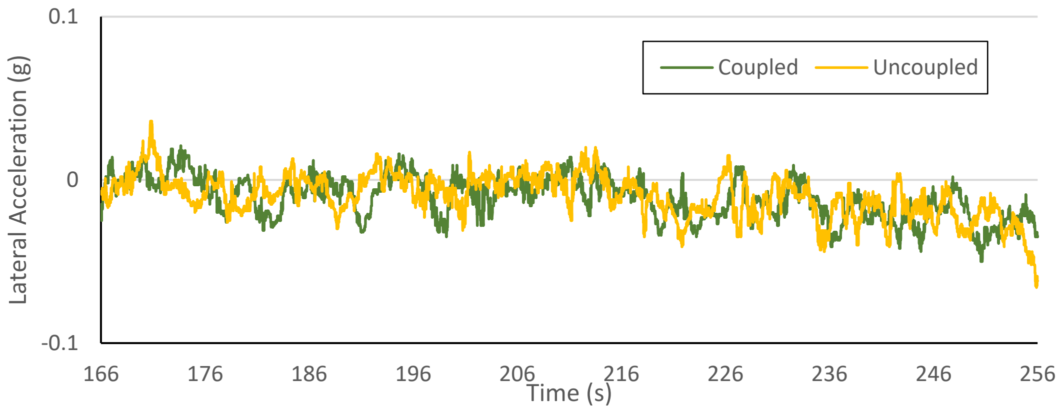

Figure 34 – Comparison of lateral acceleration for unladen 5-axle dog at 40 km/h on straight section

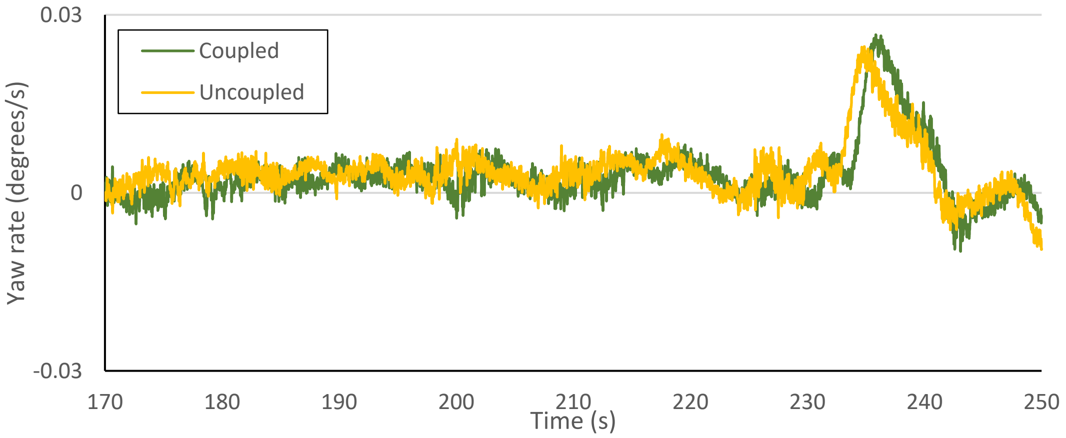

Figure 35 – Comparison of Yaw rate for unladen 5-axle dog at 40 km/h on straight section

To better understand this behaviour the lateral and longitudinal acceleration of the trailers were also plotted as a PDF, shown in Figure 36. Again this shows similar trends for both the coupled and uncoupled configurations.

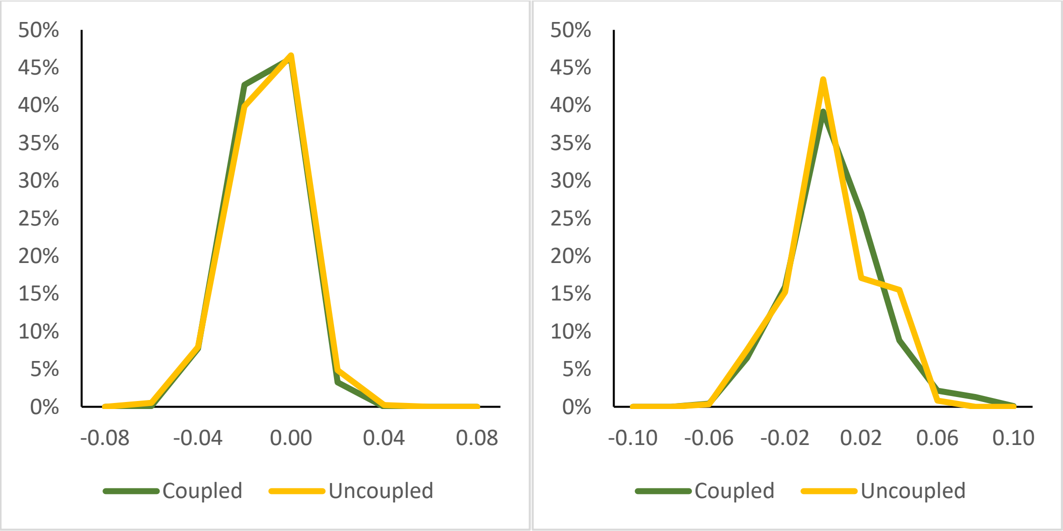

Figure 36 – PDFs of Lateral acceleration (left) and longitudinal acceleration (right) of unladen 5-axle dog at 40 km/h on straight section

The Lateral acceleration PDF in Figure 36 (left) shows a difference in the peaks at 0.00 g and -0.02 g, however the lower 0.00 g peak for the coupled run is associated with a higher -0.02 g and the general shape of the distribution is not significantly different. The small differences between the distributions are negligible and can be attributed to variance in the combination speed and path as it traversed the test track.

Further analysis has also been completed through calculation of the RMS and peak values for different units and configuration. These values are shown in Table 2.

Table 2 - RMS and Peak values for unladen 5-axle dog at 40 km/h on straight section

Value	**Parameter**	**Truck**		**Trailer**	
		Coupled	**Un-coupled**	**Coupled**	**Un-coupled**
RMS	Longitudinal accel. (g)	0.00077	0.00087	0.00090	0.00098
	Lateral accel. (g)	0.00153	0.00151	0.00260	0.00266
	Yaw rate (deg/sec)	0.316	0.322	0.575	0.574
Peak	Longitudinal accel. (g)	0.170	0.549	0.198	0.612
	Lateral accel. (g)	0.156	0.218	0.288	0.232
	Yaw rate (deg/sec)	2.210	2.614	3.247	4.043

RMS analysis shows that the lateral accelerations experienced in the un-coupled state are not significantly different to the coupled state for both the truck and the trailer. However, the RMS analysis shows that the un-coupled state does result in higher longitudinal acceleration, which is explained by the spikes noted previously. This is further demonstrated by the peak values for longitudinal acceleration being approximately three times higher for the un-coupled state than for the coupled.

When considering the lateral acceleration peak being approximately 20 per cent higher it was not immediately clear as to the reason for this. However, on evaluation of further data sets (see Table 3 and Table 4) it was concluded that the difference in peak values was a function of the noise remaining in the data and not a distinct feature of the coupling state. The results shown in Table 4 in particular show that the uncoupled state experiences a higher peak lateral acceleration on straight sections.

Finally, RMS of the yaw rate shows negligible differences between the results for the un-coupled and coupled states. However, the peak yaw rates are higher in the un-coupled state for both truck and trailer. This suggests there are periods where the truck and trailer have a faster lateral sway (as observed by higher peak yaw rates) however for the most part are the same (as observed by similar RMS yaw rates).

Negotiating curves at constant speed

In the curve at constant speed test there is a consistent negative lateral acceleration and positive yaw rate for both coupling states on the trailer. This is an expected result due to the relatively constant turning radii of the AARC highway circuit. This are shown in Figure 37 and Figure 38.

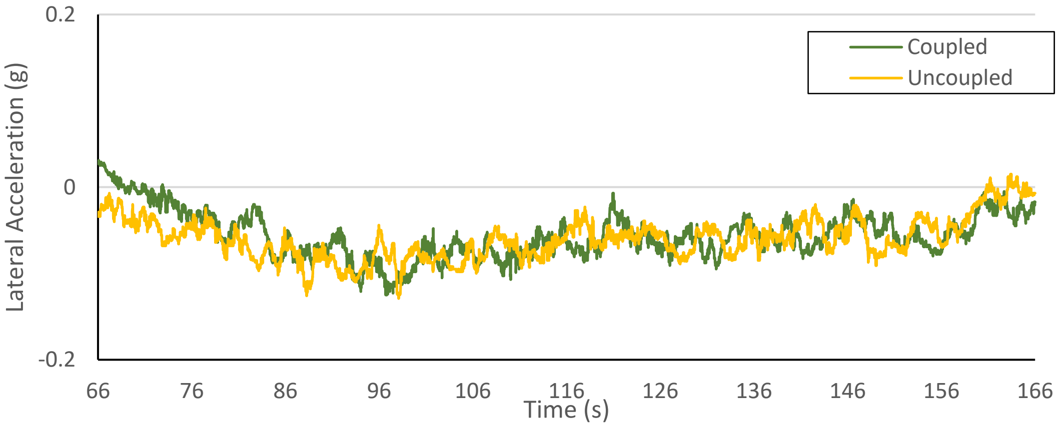

Figure 37 – Comparison of lateral acceleration for unladen 5-axle dog at 40 km/h on turns 1 & 2

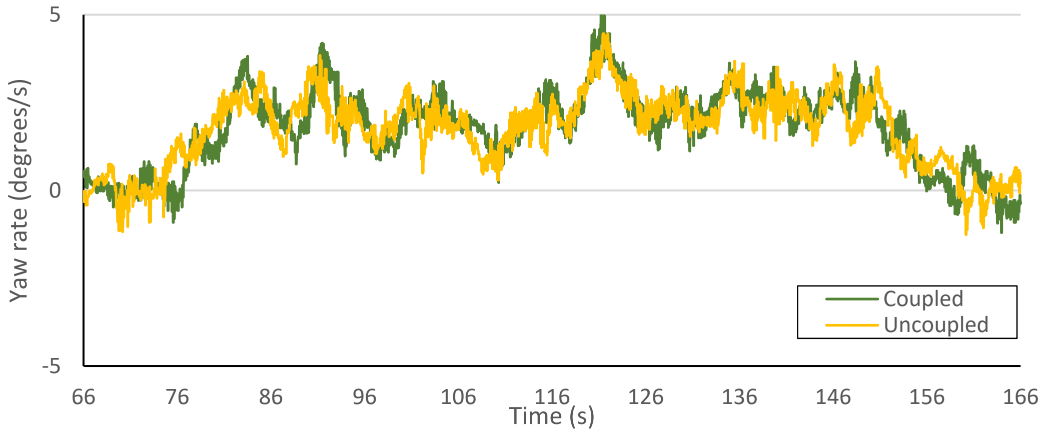

Figure 38 – Comparison of Yaw rate for unladen 5-axle dog at 40 km/h on turns 1 & 2

The longitudinal acceleration, shown in Figure 39, follows the same trend for both coupling states as the combination traverses the elevation changes and gradient changes that were present through turns 1 & 2 of the circuit. Both the uncoupled and coupled cases reach similar magnitudes, however, as was observed during the straight-line data there are brief but significant spikes in the longitudinal acceleration of the uncoupled case. Again these spikes are explained by the drawbar pushing and pulling as it travels backwards and forwards in its range of travel due to the chains.

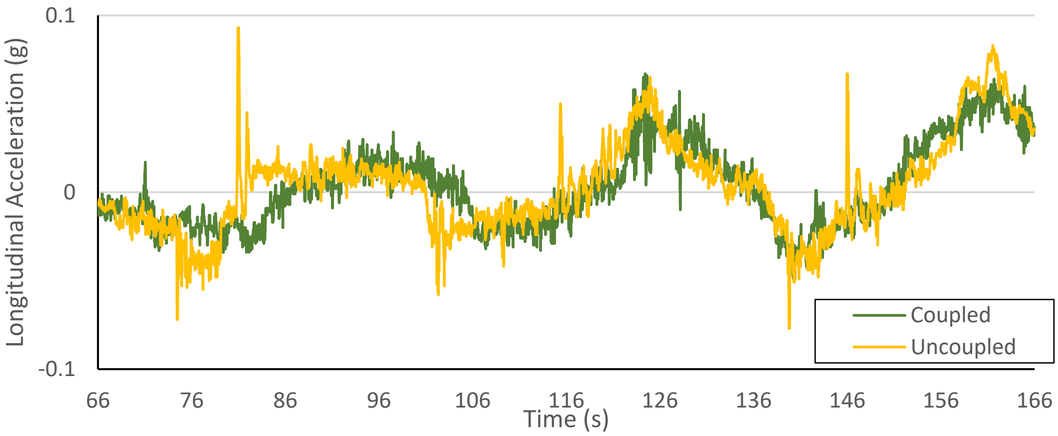

Figure 39 – Comparison of longitudinal acceleration for unladen 5-axle dog at 40 km/h on turns 1 & 2

Figure 40 shows the PDF of the lateral acceleration and yaw rate of the trailer in different coupling states. In the PDF for the lateral acceleration and yaw rate the coupled and un-coupled runs produce similar distributions with no significant differences.

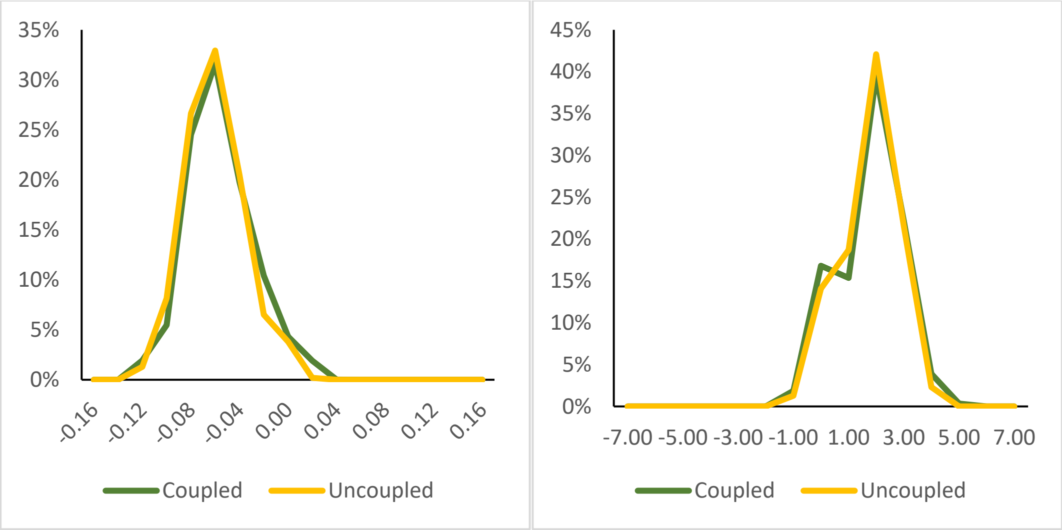

Figure 40 – PDFs of Lateral acceleration (left) and yaw rate (right) of unladen 5-axle dog at 40 km/h on turns 1 & 2

This is further supported in the numerical analysis (shown in Table 3) of the data which shows no significant differences between the RMS and peak values of lateral acceleration or yaw rate. There is however a significantly larger RMS result for both the truck and trailer's longitudinal acceleration. The uncoupled runs experience RMS of longitudinal acceleration 35 per cent higher for the truck and 40 per cent higher for the trailer when compared to the coupled state. The peak values are also significantly higher for the uncoupled runs. This is explained by the previously observed spikes in longitudinal acceleration data.

Table 3 – RMS and Peak values for unladen 5-axle dog at 40 km/h on turns 1 & 2

Value	**Parameter**	**Truck**		**Trailer**	
		Coupled	**Un-coupled**	**Coupled**	**Un-coupled**
RMS	Longitudinal accel. (g)	0.00096	0.00130	0.00073	0.00102
	Lateral accel. (g)	0.00859	0.00866	0.00480	0.00477
	Yaw rate (deg/sec)	5.467	5.326	6.259	6.132
Peak	Longitudinal accel. (g)	0.145	0.655	0.117	0.597
	Lateral accel. (g)	0.422	0.426	0.272	0.257
	Yaw rate (deg/sec)	7.592	6.394	6.152	6.138

Negotiating slalom at constant speed

As the combination travels through the slalom maneouver, consistent lateral acceleration and yaw rate behaviour is observed between the coupled and un-coupled runs. These are shown in Figure 41 and Figure 42.

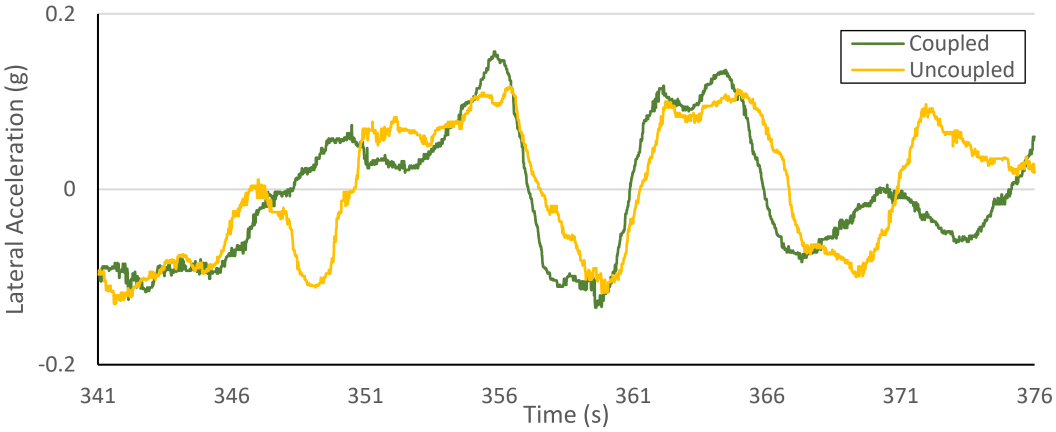

Figure 41 – Comparison of lateral acceleration for unladen 5-axle dog at 40 km/h through the slalom

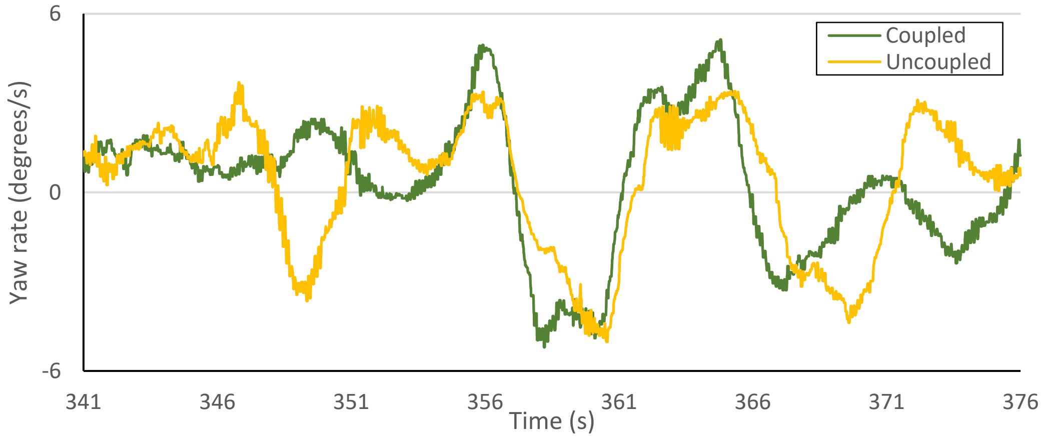

Figure 42 – Comparison of yaw rate for unladen 5-axle dog at 40 km/h through the slalom

The lateral acceleration moves between positive values approximately 0.15g in magnitude, while the yaw rate exhibits similar behaviour up to approximately 5 degrees/s in magnitude. Although there are differences between the uncoupled and coupled case's lateral acceleration and yaw rate behaviour, they do not show any consistent trend in their differences, suggesting the different behaviour can be mostly attributed to small differences in vehicle path or speed.

The longitudinal acceleration has been shown in Figure 43.

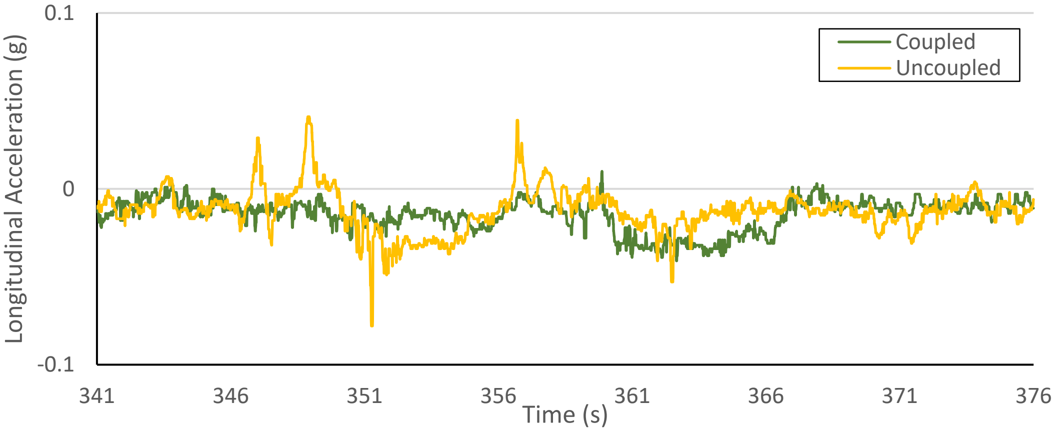

Figure 43 – Comparison of longitudinal acceleration for unladen 5-axle dog at 40 km/h through the slalom

For longitudinal acceleration the differences between the two coupling cases are clearer. As already observed in previous analysis, there are significant spikes in the longitudinal acceleration from where the trailer is either pushing or pulling as it reaches the limits of its available range of longitudinal motion.

The PDF of each coupling state has also been plotted in Figure 44.

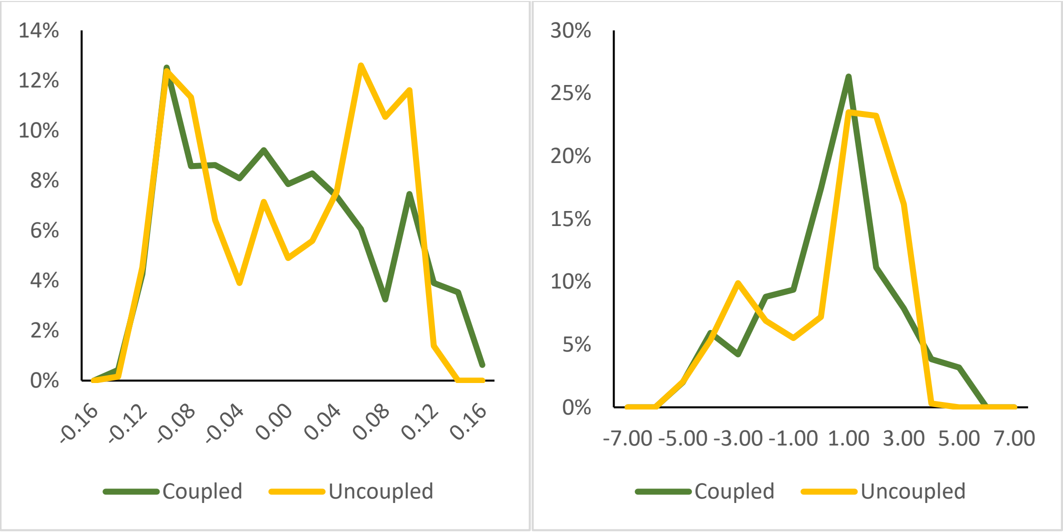

Figure 44 – PDFs of Lateral acceleration (left) and yaw rate (right) of unladen 5-axle dog at 40 km/h through the slalom

In the case of the lateral acceleration an interesting difference is noted between the coupled and uncoupled cases. The uncoupled case includes two peaks corresponding to approximately equivalent left and right acceleration of the trailer, which is the expected result. The coupled trailer however has a similar negative acceleration peak but no clear positive acceleration peak, instead the acceleration varies more widely suggesting it did not stabilise during the right turns. In the case of the yaw rate of the trailer, both cases have a discernible peak yaw rate which is maintained, although there is a slight bias towards positive yaw-rate. This is possibly caused by an inherent bias in the driver to take a right turn slightly more sharply than a left turn during the slalom. Nevertheless, both results are relatively similar.

When analysing the RMS values for each case, shown in Table 4, similar results for lateral acceleration and yaw rate are observed. A significantly larger peak lateral acceleration was observed for the trailer, however noting that the RMS values are similar suggests that this is likely an anomalous value. Longitudinal acceleration again showed significantly higher RMS and peak values for the un-coupled case when compared to the coupled case.

Table 4 – RMS and Peak values for unladen 5-axle dog at 40 km/h through the slalom

Value	**Parameter**	**Truck**		**Trailer**	
		Coupled	**Un-coupled**	**Coupled**	**Un-coupled**
RMS	Longitudinal accel. (g)	0.00046	0.00090	0.00066	0.00115
	Lateral accel. (g)	0.00861	0.00798	0.00922	0.00953
	Yaw rate (deg/sec)	7.657	6.687	5.654	5.779
Peak	Longitudinal accel. (g)	0.118	0.568	0.194	0.672
	Lateral accel. (g)	0.272	0.288	0.366	0.483
	Yaw rate (deg/sec)	7.092	6.185	6.17	6.07

Braking from constant speed

Figure 45 shows the longitudinal acceleration of the combination during the braking maneouver. During the braking manoeuvres the longitudinal acceleration drops sharply to approximately 0.3-0.4 g for laden load cases and 0.4-0.5 g for unladen load cases and maintains this acceleration for the length of the braking until quickly returning to zero once the vehicle has come to a stop. There are some residue oscillations however these dissipate over 1 to 3 seconds.

This observed behaviour is consistent across all speeds, coupling states and trailer axle configurations. The only observable differences are the spikes in longitudinal acceleration which are present in the uncoupled runs. These spikes are seen as negative acceleration for the truck and positive acceleration for the trailer because the cause of the spike is the trailer braking harder than the truck. This results in the trailer pulling tightly on the chains and dragging the truck backwards, after which the trailer is consequently then pulled forward by the truck.

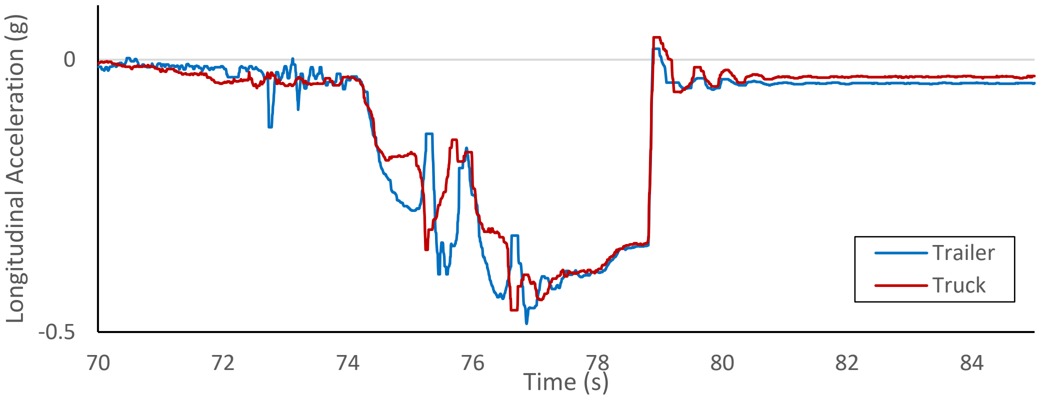

Figure 45 – Longitudinal acceleration for uncoupled unladen 5-axle dog braking from 40 km/h

Figure 46 shows a comparison between uncoupled and coupled runs where the spikes are obvious. Where the coupled trailer exhibits a smooth consistent longitudinal acceleration under braking the uncoupled trailer's acceleration is significantly less consistent.

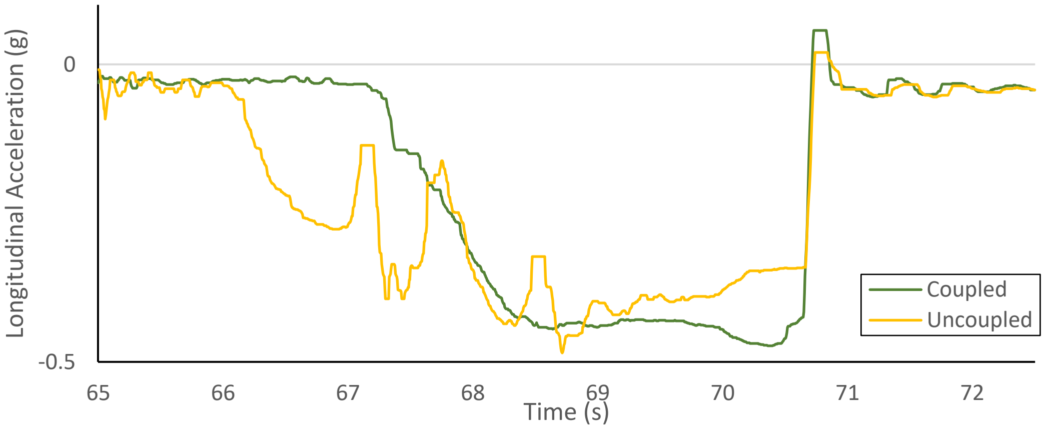

Figure 46 – Comparison of longitudinal acceleration for unladen 5-axle dog braking from 40 km/h

Figure 47 and Figure 48 show the same braking maneouver with lateral acceleration and yaw rate plotted. The lateral acceleration plots show that there are small variations in the lateral acceleration during the braking manoeuvre, with larger variance seen in the trailer than the truck. The same behaviour is seen when examining yaw rate. These larger yaw rates and lateral accelerations quickly dissipate during the braking manoeuvre and do not cause any significant instability as recorded by the driver or chase car observations.

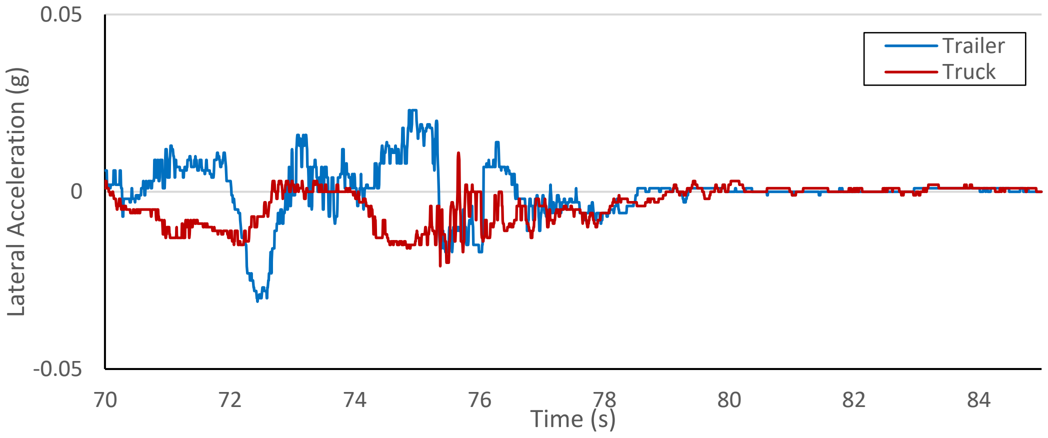

Figure 47 – Lateral acceleration for uncoupled unladen 5-axle dog braking from 40 km/h

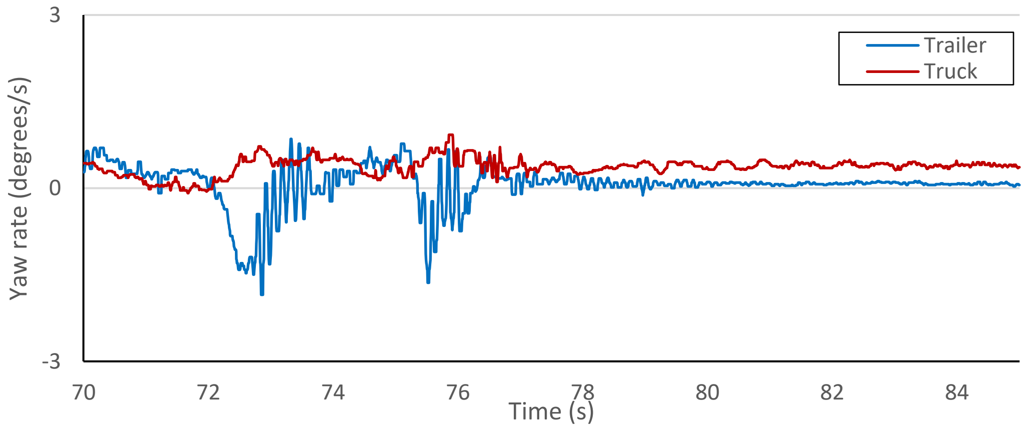

Figure 48 – Yaw rate for uncoupled unladen 5-axle dog braking from 40 km/h

In comparison to the lateral acceleration a larger magnitude of variance can be seen for the yaw rate. This disruption in yaw acceleration is only present in the trailer of the combination and does not show any transfer to the truck. The disruption in yaw rate and lateral acceleration quickly dissipates during the braking manoeuvre, not causing any significant instability during the manoeuvre.

To directly compare the two coupling states, Figure 49 and Figure 50 show the lateral acceleration and yaw rate of a trailer.

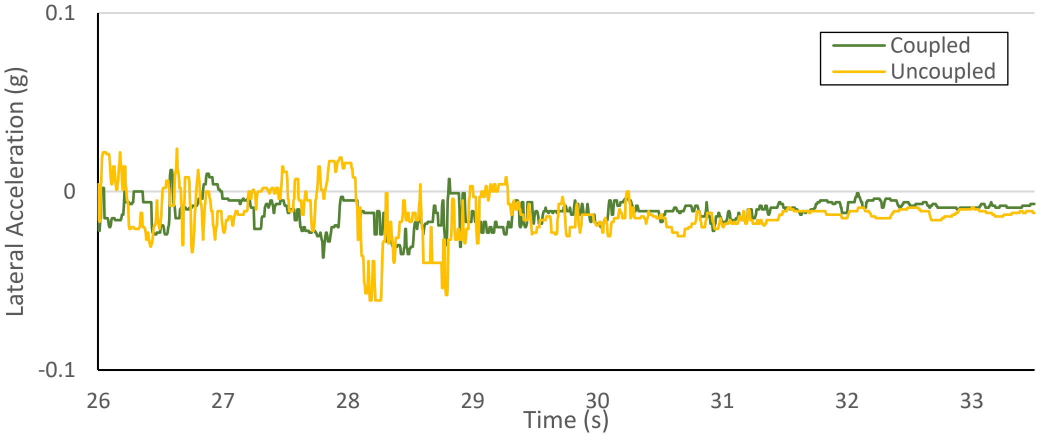

Figure 49 – Comparison of lateral acceleration for unladen 5-axle dog braking from 40 km/h

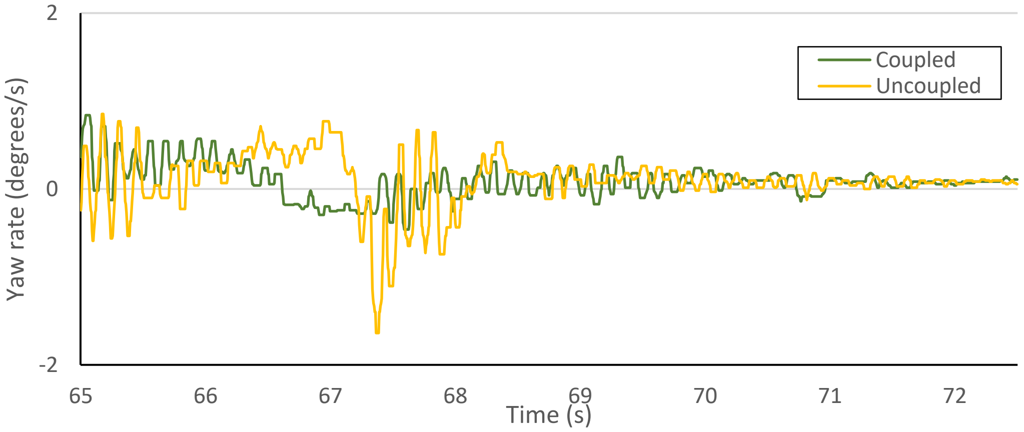

Figure 50 – Comparison of lateral acceleration for unladen 5-axle dog braking from 40 km/h

In both cases, the uncoupled trailer experiences slightly larger variations in the measured parameters, however in both cases the values are well within safe operating levels for controlling the vehicle.

Coupling release while in motion

The decoupling of the dog trailer results in a large spike in longitudinal acceleration as the slack in the safety chain is taken up and the trailer pulls on the truck. This can be seen in Figure 51 where after initial disengagement the trailer separates from the trailer for two seconds while the chains are still slack (shown with a dashed red line). Once the chains tighten there is an immediate spike shown at 172 seconds. After this spike the observed behaviour of the combination returns to similar behaviour as the previously shown uncoupled behaviour.

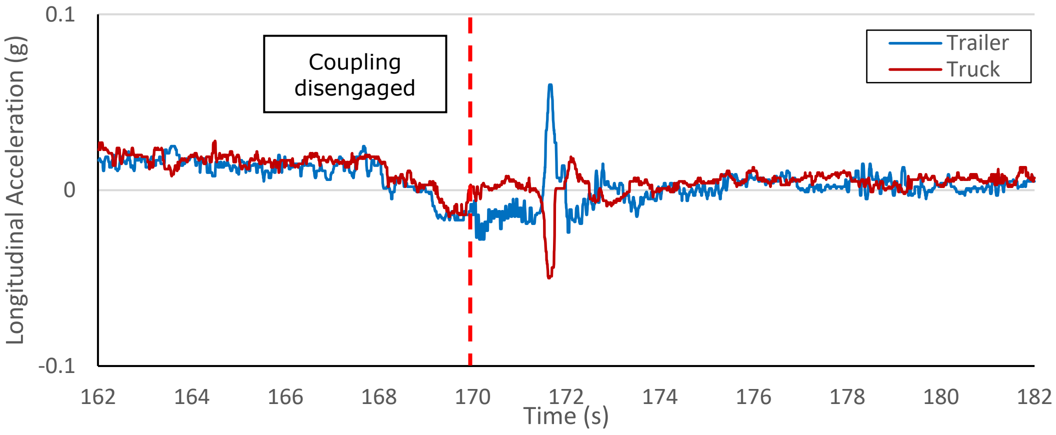

Figure 51 – Longitudinal acceleration of unladen 5-axle dog uncoupling on a straight

This aligns with driver comments noting that there was an initial delay between the coupling disengages during motion and when they felt the effect of the disengagement.

In the cases of lateral acceleration and yaw rate, shown in Figure 52 and Figure 53, there is no noticeable affect to Lateral acceleration or yaw rate at or near the point of decoupling. There were no distinguishable differences pre and post coupling disengagement.

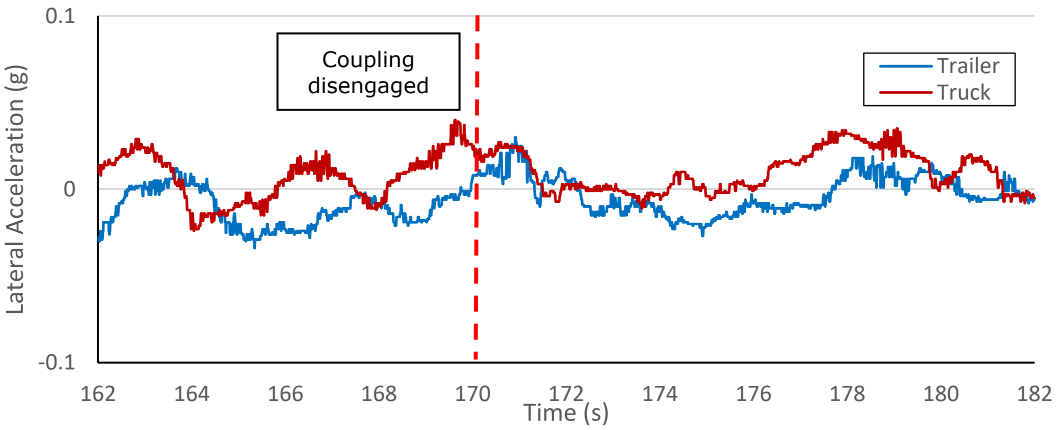

Figure 52 – Lateral acceleration of unladen 5-axle dog uncoupling on a straight

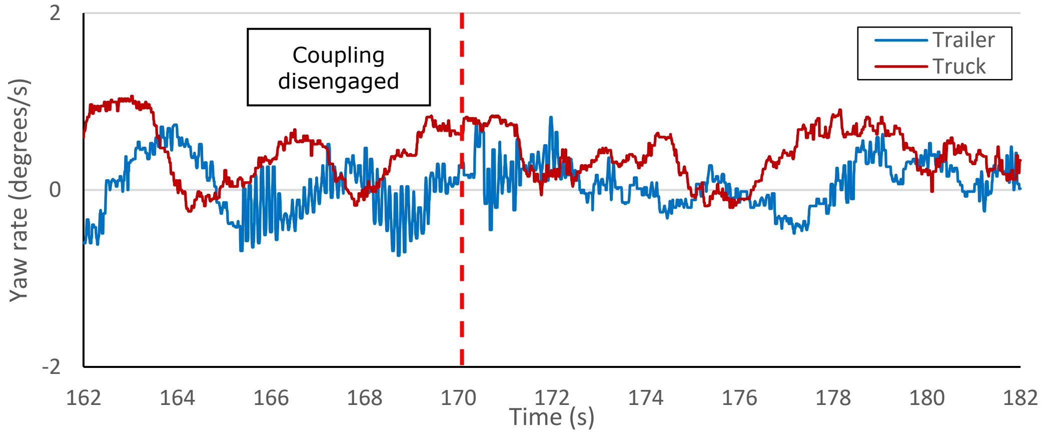

Figure 53 – Yaw rate of unladen 5-axle dog uncoupling on a straight

Similar behaviour is observed when the decoupling occurs during a turn, shown in Figure 54 to Figure 56. There is a large spike in longitudinal acceleration shortly after the point of decoupling which quickly dissipates, and the behaviour returns to the same as before the decoupling occurred.

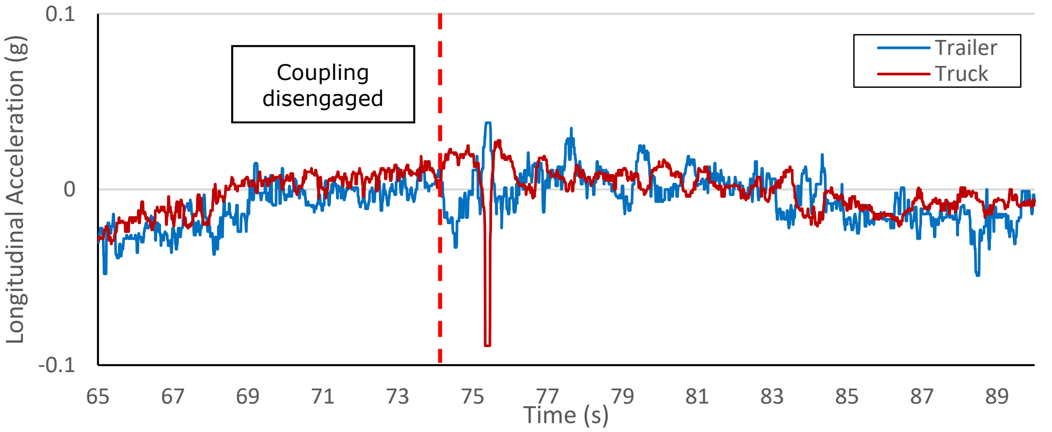

Figure 54 – Longitudinal acceleration of unladen 5-axle dog uncoupling on a turn

In the case of the lateral acceleration and the yaw-rate there is no discernible differences between before and after the coupling is disengaged.

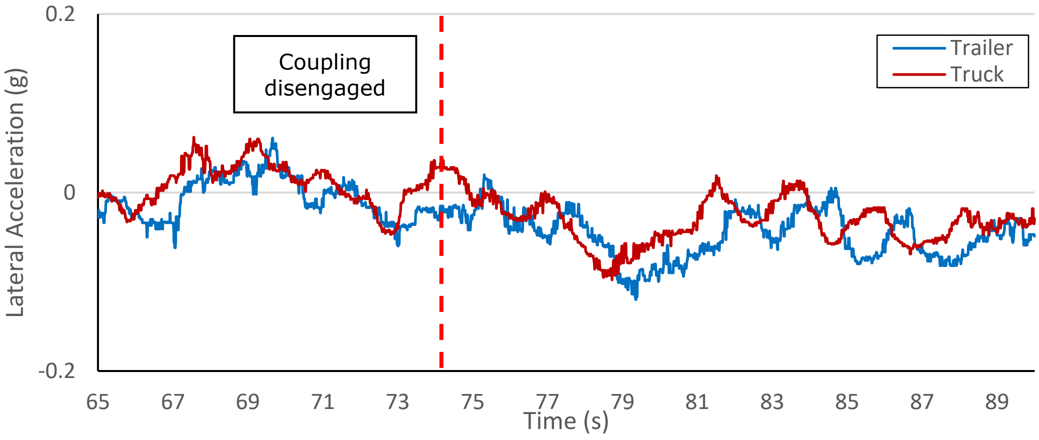

Figure 55 – Lateral acceleration of unladen 5-axle dog uncoupling on a turn

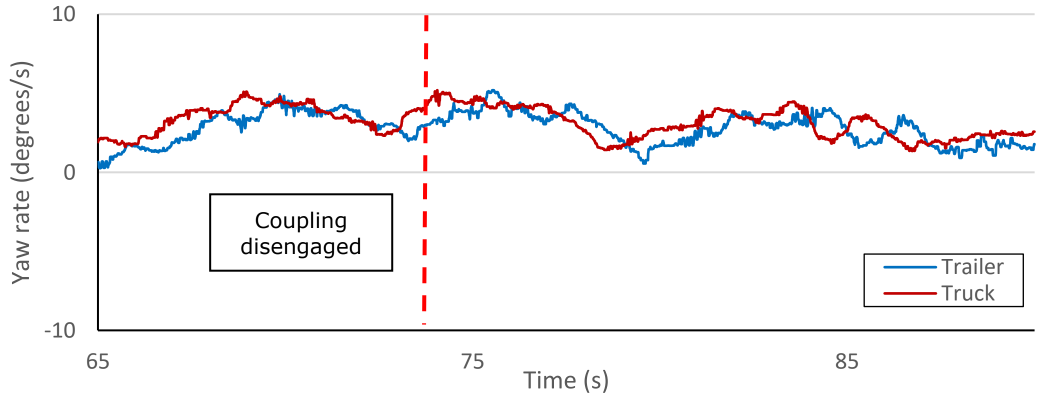

Figure 56 – Yaw rate acceleration of unladen 5-axle dog uncoupling on a turn

Effect of coupling failure type

The effect of different coupling failure types was tested by removing the tow-coupling funnel to investigate the differences in behaviour if the drawbar tow-eye was not contained within the tow-coupling funnel.

The largest observed difference with the funnel removed was the severity of the push and pulling in the longitudinal direction, which was also highlighted by the driver feedback. This phenomenon was also observed in the recorded data, especially during the braking manoeuvre where there were large sharp spikes in longitudinal acceleration for both the truck and trailer. These spikes occurred at the start of the braking manoeuvre, as the trailer decelerated faster than the truck it built up a speed differential and began pulling away from the trailer, taking up the slack in the safety chains. When all the slack was taken out of the chains the trailer pulled on the chains resulting in a large force exerted through the chains pulling the truck rearward and the trailer forward as their difference in speed was neutralised. This spike can clearly be observed Figure 57.

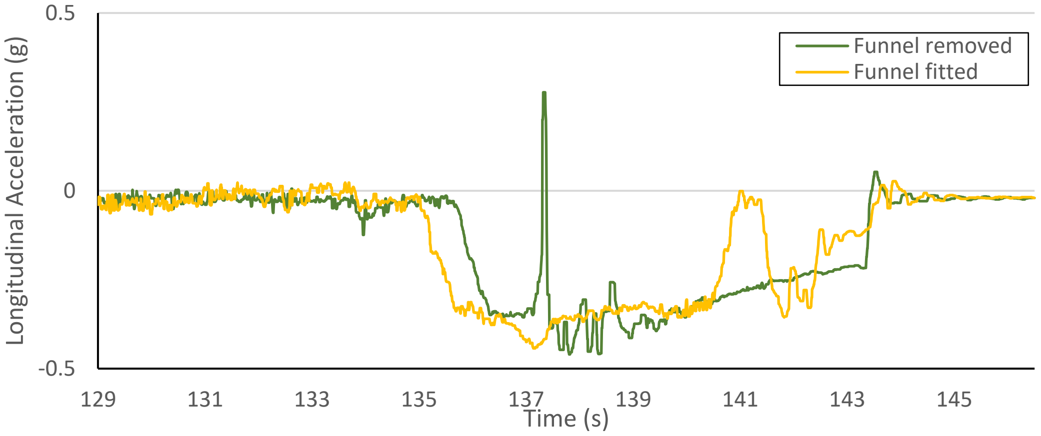

Figure 57 – Longitudinal acceleration of unladen 5-axle dog braking from 40 km/h

.This resulted in high peak accelerations, which can be seen in Table 5. As demonstrated in the table there is no clear trend with respect to vehicle speed, with the highest peak force occurring during the braking from 40 km/h test but also the peak force for the 80 km/h test being higher than at 60 km/h. Note that the values shown in Table 5 are unfiltered results as the peak spike forced are brief and a filter would considerably reduce the magnitude of the spikes.

Table 5 – Peak accelerations of uncoupled unladen 5-axle dog braking from 40 km/h

Parameter	**40 km/h**		**60 km/h**		**80 km/h**	
	Funnel fitted	Funnel Removed	Funnel fitted	Funnel Removed	Funnel fitted	Funnel Removed
Truck Peak Longitudinal accel. (g)	-0.477	-2.355	-0.540	-1.966	-0.490	-2.122
Trailer Peak Longitudinal accel. (g)	-0.460	1.382	-0.572	1.164	-0.458	1.366

In the cases of lateral acceleration and yaw rate, shown in Figure 58 and Figure 59, it can be seen that in the tests with the funnel removed there is a noticeable effect from the spike in longitudinal acceleration, but only a minor increase in lateral acceleration and yaw rate occurring shortly after the longitudinal acceleration spike. This small increase dissipates, and no overall stability problems appear. Interestingly, in these scenarios the magnitude of the peak lateral acceleration and yaw rate is reduced compared to when the funnel is fitted.

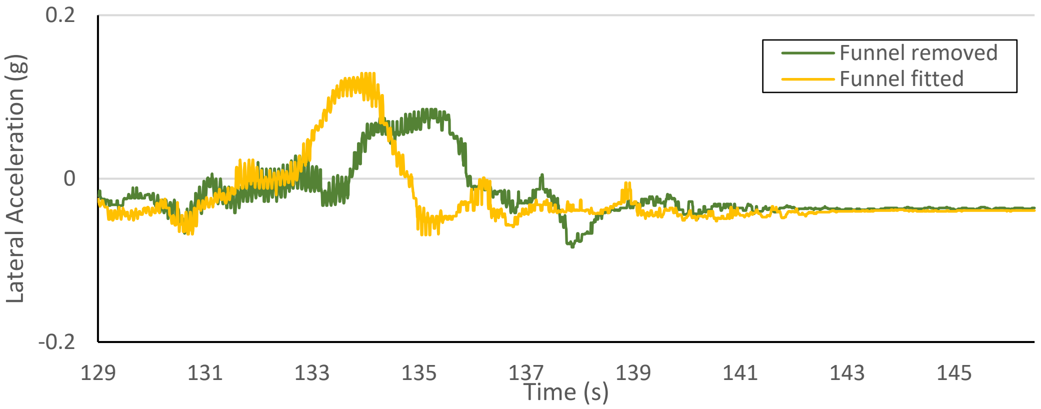

Figure 58 – Lateral acceleration of uncoupled unladen 5-axle dog on turn 1 & 2

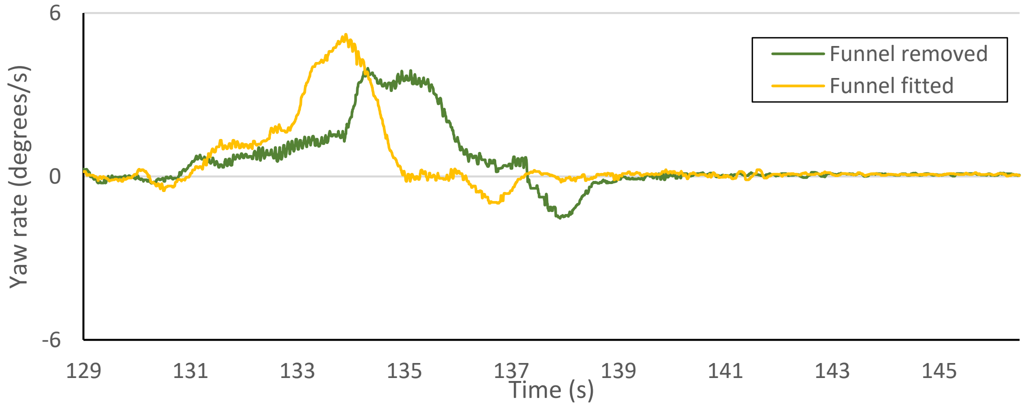

Figure 59 – Yaw rate of uncoupled unladen 5-axle dog on turn 1 & 2

3.3 Considerations for effective use of safety chains

Any future regulatory guidance regarding the fitment and/or retro fitment of safety chains to heavy vehicles would benefit from taking into account the following elements:

- Chains must be crossed
- Chain attachment must be as near as practicable to the coupling
- Safety chain attachment strength must be sufficient
- An appropriate safety chain attachment location must be selected
- An appropriate chain and chain length must be selected.

Chains must be crossed

Crossing chains 'catches' the drawbar, limiting how far down the drawbar can drop.

Crossed chains limit the amount of sideways deflection. In practice when the trailer is being towed using chains, it tends to drift to one side or the other, and index into that position until a counter force causes it to move - such as turning a corner. The transverse drawbar deflection while underway was observed to be within ±200mm of the coupling point.

Crossed chains tended to nest within each other, limiting sway or 'swing' while underway.

Chain attachment must be as near as practicable to the coupling

ADR62/02 requires safety chain attachments to be proximal to the coupling points.

The towbar requirement clause is: 13.4.1. Except for vehicles designed for use in 'Road Trains,' the 'Towbar' must be fitted with two safety chain attachments, mounted either side of and adjacent to, the tow 'Coupling.'

The drawbar requirement clause is: 14.4.1. Any safety chain attachment point affixing a safety chain to a 'Drawbar' must be located as near as practicable to the 'Coupling.' Where two points of attachment are required, they must be mounted one on either side of the centreline of the 'Drawbar'.

The ADR62/02 requirements as worded are subject to interpretation. Based on the observations of the drawbar movement in relation to the impact forces while underway, it is recommended that the wording with reference to the location of safety chain attachments is further refined to emphasise the need for the safety chain attachment points to be close to the coupling points, with the consideration of maximum distance parameters to be prescribed, with any necessary exceptions subject to a performance clause.

Safety chain attachment strength must be sufficient

ADR62/02 currently outlines the safety chain attachment strength requirements. The testing validated that these strength requirements are suitable.

The substrate to which the safety chain attachments are attached must be structurally significant. ADR62/02 currently implies that this fitment must also be able to withstand the same forces that the safety chain attachment is tested to. It is recommended that this strength requirement is further clarified by allowing validation by calculation of this strength.

An appropriate safety chain attachment location must be selected

The chain pathway must take into account the objective of retaining effective control lines - air and electrical systems for braking and lighting. This means ensuring no pinch points, limited rubbing, etc.

Typically the trailer side chains are attached permanently or semi-permanently.

User ergonomics should be considered when locating the safety chain attachments on the truck towbar. If a clevis pin-type safety chain attachment is used, then the pin slide direction and use should be considered in relation to operator position.

An appropriate chain and chain length must be selected

The chain length must be carefully selected in order to ensure that the length allows full articulation, while not allowing the drawbar to drag on the ground in the event of disconnection.

The chain grade is prescribed in ADR62/02. Given supply and availability factors, it is recommended that stronger chain grades are allowed by prescribing the Grade T chain as a minimum performance standard. At the time of writing higher grades of chain manufactured to the same Standard and matching the same geometry are more commonly available than Grade T chain. Relaxing this requirement would help to clarify the intent of the Standard and enable a broader supply.

The measured forces between vehicles did not suggest that the chain had a role in absorbing the forces between vehicles. Therefore, any application that uses heavier chains than the minimum prescribed chain strength is equally capable of performing its function for the purposes of retaining a redundant connection. This fact will be useful when planning fleet operations in which it may be desirable to decide on standard chain sizes for interoperability purposes.

The high-grade chains in use for heavy vehicles are highly tolerant to corrosion. The surface of these chains typically exhibits only shallow surface corrosion typical of high tensile steel, which remains a stable protective surface throughout the life of the product. There is no evidence to suggest that the strength of these chains diminishes over time due to corrosion in normal operating conditions.

3.4 Risk management considerations

This section outlines the reasoning behind increased risk management as the risk profile of the Australian heavy vehicle fleet increases as well as how safety chains act as a redundancy system to assist with the risk management.

Increasing risk profile

The risk profile of high productivity vehicles in Australia will increase over time due to several related factors:

- Higher numbers of high productivity vehicles in use. These include the increased use of:
    - 4-axle dog trailer combinations
    - 5-axle dog trailer combinations
    - 6-axle dog trailer combinations
    - A-double combinations.
- Trends for increasing productivity by increasing the typical combination mass
- The higher numbers of high productivity vehicles require more skilled drivers than are available - drawing from an increasingly lower skilled and less experienced pool of drivers. This contrasts with highly selective and strict driver conditions that characterised the early introduction and development of HPVs in Australia.
- As HPVs are allowed on more road categories in Australia, they have more regular contact with higher density populations, and therefore the risk profile increases. The probability of interaction with the community, and therefore the risk of injury and death, increases due to both the potential harm caused by a disconnection, and the higher exposure due to increasing quantity of HPV near populated areas.
- Most elements of road safety infrastructure are not optimised to control high productivity vehicles. Examples include:
    - Energy absorbent barriers.
    - Wire rope barriers.
    - Impact attenuators
    - Traffic separation bollards.
- Heavy vehicles are not designed to optimise the safe collision interaction with light passenger vehicles. This means that light vehicle safety systems, such as air bags and crumple zones, are often not effective in the event of a collision with a heavy vehicle.
    - There is no performance requirement on most rear underrun protective devices.
    - There is no requirement for side impact protective devices on most heavy vehicles.

Load path redundancy and safety systems

Currently, the use of safety chains on high productivity vehicle such as 4, 5, and 6 axle dogs and A-double combinations is not common. Therefore if a coupling or connection fails, the trailer disconnects entirely, and depending on the road topography and relative speeds the trailer will separate from the truck. This causes the airlines to break, which allows the spring-loaded trailer brakes to engage, bringing the trailer to an uncontrolled sudden stop.

This safety measure has its limitations from the perspective of a safe system and poses a significant risk to the community if the uncontrolled trailer collides with other road users, pedestrians or infrastructure. In most operational situations it would not be unusual for the trailer to changes lanes, leave the road, or otherwise cause a hazard by suddenly stopping on a busy road.

Typically for mature engineering applications such as aerospace, the use of components without load redundancy can be tolerated, but only in a quality controlled and highly regulated and monitored environment. This typically would involve quality assurance processes and trained, professional and well-resourced practitioners. The use of quality control systems such as ISO9001 or better would be expected. However, in the heavy vehicle operation and maintenance industry in Australia, the use of a formal quality system is rare.

The rigors of road transport involve complex logistics, personnel, and interchanging combinations in sometimes adverse conditions. Maintenance to a high standard of practice cannot realistically be expected to be always applied in all scenarios for all combinations.

It is important, therefore, that community confidence in high productivity vehicles is established and maintained, with the use of suitably robust redundant systems to ensure a safe combination in the event of critical component failure or user error.

3.5 Conclusions

The success of the Advantia led research program into 4, 5, and 6-axle dog trailers increases community confidence regarding the safety and stability of the use of safety chains as a connection redundancy measure.

The testing program incorporated both steady state and dynamic manoeuvres both with the trailer uncoupled (connected only by safety chains) and fully coupled to set a baseline standard. In the cases of trailer handling, yawing and lateral control of the truck and trailer no major issues were identified. Depending on the failure type of the coupling and speed of the combination the main issues identified were that the driver may not immediately identify that the trailer has disconnected. The trailer otherwise performed similarly to the baseline case when only connected by safety chains.

The primary difference in observed performance was that depending on the failure type, the shunting and pulling between the truck and trailer may be significantly increased compared to the baseline case. This was only significant in cases when the tow-eye was not constrained by the coupling sleeve. Nevertheless, even with this additional shunting and pulling, the driver's ability to safely control the combination was not impacted. In fact, the shunting and pulling on the hauling unit may be beneficial in quickly alerting the driver that trailer separation has occurred.

The results provide considerable confidence as to the safety of the use of heavy chains which can be fitted in order to retain a redundant coupling mechanism between truck and trailer. In doing so, the air and electrical services are also retained, and therefore the trailer remains in control until the operator can safely drive the vehicle to a suitable location for inspection.

Appendix A Subject combination details

Truck & 5-axle dog

Table 6 – Truck & 5-axle dog specifications

Truck	
Make	Kenworth
Model	T403
VIN	6F5000000DA450880
Engine	Cummins ISXe5 450hp
GCM (maximum rated)	70,000 kg
GVM (maximum rated)	26,500 kg
Tare mass	10,500 kg
Suspension (steer)	Kenworth Parabolic 7.2t
Suspension (drive)	Kenworth Airglide 460
Trailer	
Make	Chris's Body Builders
Model	CBBDT-5 (tipper)
VIN	6B9TR5DOGDSCB8944
ATM (maximum rated)	41,500 kg
Tare mass	8,300 kg
Suspension	York Duratrac

Table 7 – Truck & 5-axle dog PBS results

Technical Results Table – Truck & 5-axle dog				
Performance Standard	**Performance results**		**Performance level (L1 to L4; P for Pass or F for Fail)**	
	N/A – L1	63.0t – L2		
Safety Standards				
1. Startability	N/A	17.7%	N/A	L1
2. Gradeability:				
a) Maximum grade	N/A	20.8%	N/A	L1
b) Speed on a 1% grade	N/A	86.2 km/h	N/A	L1
3. Acceleration capability	N/A	20.2 s	N/A	L2
5. Tracking Ability on a Straight Path	N/A	2.93 m	N/A	L2
7. Low-Speed Swept Path	7.43 m		L2	
8. Frontal Swing:				
a) Maximum Frontal Swing	0.85 m		P	

b) Maximum of Difference	0.03 m		P	
c) Difference of Maxima	-0.75 m		P	
9. Tail Swing	0.04 m		L1	
10. Steer-Tyre Friction Demand	17%		P	
11. Static Rollover Threshold (Worst)	N/A	0.35 g	N/A	P
Static Rollover Threshold of last unit	N/A	0.36 g	N/A	P
12. Rearward Amplification	N/A	1.89	N/A	P
13. High-Speed Transient Off-tracking	N/A	0.80 m	N/A	L2
14. Yaw Damping Coefficient	N/A	0.26	N/A	P
16. Directional stability under braking	ABS / EBS / LPV		P	
Infrastructure Standards				
17. Pavement Vertical Loading	GML / CML / HML		P	
18. Pavement Horizontal Loading	Meets standard		L1	
19. Tyre Contact Pressure Distribution	Prescriptive		P	
20. Bridge Loading	Tier 1		P	

Truck & 6-axle dog

Table 8 – Truck & 6-axle dog specifications

Truck	
Make	Kenworth
Model	T403
VIN	6F5000000DA450880
Engine	Cummins ISXe5 450hp
GCM (maximum rated)	70,000 kg
GVM (maximum rated)	26,500 kg
Tare mass	10,500 kg
Suspension (steer)	Kenworth Parabolic 7.2t
Suspension (drive)	Kenworth Airglide 460
Trailer	
Make	Hercules Engineering
Model	HEDT-6
VIN	6T9T24V97B0AFH170
ATM (maximum rated)	47,000 kg
Tare mass	9,300 kg
Suspension	SAF Intradisc

Table 9 – Truck & 6-axle dog PBS results

Technical Results Table – Truck & 6-axle dog				
Performance Standard	**Performance results**		**Performance level (L1 to L4; P for Pass or F for Fail)**	
	N/A – L1	68.5t – L2		
Safety Standards				
1. Startability	N/A	16.1%	N/A	L1
Gradeability:				
a) Maximum grade	N/A	19.1%	N/A	L2
b) Speed on a 1% grade	N/A	75.9 km/h	N/A	L2
3. Acceleration capability	N/A	21.1 s	N/A	L2
5. Tracking Ability on a Straight Path	N/A	2.88 m	N/A	L1
7. Low-Speed Swept Path	8.16 m		L2	
8. Frontal Swing:				
a) Maximum Frontal Swing	0.78 m		P	
b) Maximum of Difference	0.02 m		P	
c) Difference of Maxima	-0.64 m		P	
9. Tail Swing	0.04 m		L1	
10. Steer-Tyre Friction Demand	18%		P	
11. Static Rollover Threshold (Worst)	N/A	0.35 g	N/A	P
Static Rollover Threshold of last unit	N/A	0.49 g	N/A	P
12. Rearward Amplification	N/A	1.85	N/A	P
13. High-Speed Transient Off-tracking	N/A	0.63 m	N/A	L2
14. Yaw Damping Coefficient	N/A	0.34	N/A	P
16. Directional stability under braking	ABS / EBS / LPV		P	
Infrastructure Standards				
17. Pavement Vertical Loading	GML / CML / HML		P	
18. Pavement Horizontal Loading	Meets standard		L1	
19. Tyre Contact Pressure Distribution	Prescriptive		P	
20. Bridge Loading	Tier 1		P	

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