National Heavy Vehicle Regulator

HVSI Project 557
Testing of electronic stability control technologies on long combination vehicles

NTRO project number: 00054

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Summary

This report presents the outcomes of HVSI Project 557, which investigated the effectiveness and performance of electronic braking systems, specifically with Roll Stability Control (RSC) on Performance Based Standards (PBS) combination vehicles. The project was initiated to support the potential inclusion of stability system requirements within the PBS scheme rules, ensuring PBS vehicles continue to set the benchmark for heavy vehicle safety on Australian roads.

The project comprised two primary components:

- In-service monitoring, which collected operational data from a large fleet of heavy vehicles including PBS A-double combinations fitted with RSC over a 24-month period. This stage examined the frequency of system interventions and faults, providing insights into how often stability systems engage under real-world conditions and the importance of maintaining system functionality.
- Field testing, which involved controlled high-speed lane change manoeuvres using a representative PBS A-double combination. Testing was conducted across two configurations with different centre of gravity (CoG) heights as well as a range of RSC activation states to assess impacts on lateral acceleration, rearward amplification (RA), yaw rate, and body roll. Comparisons were also made with PBS simulation results.

The testing demonstrated that RSC significantly improved vehicle stability, reducing RA and preventing rollovers even in high-severity manoeuvres. Notably, field tests showed that a high CoG A-double that failed RA requirements in simulation could satisfy PBS dynamic performance criteria when equipped with active RSC. In-service data further highlighted that while RSC interventions are effective and occur in the field, the high number of detected system faults underscores the need for policies that also address ongoing operational compliance.

Based on these findings, the report supports the case for incorporating stability systems into PBS requirements, alongside measures to ensure systems remain functional in service such as real-time status reporting or visual indicators. This work provides critical evidence and dataset to inform future policy development, including the NHVR's review of the PBS scheme, aimed at enhancing the safety and productivity of Australia's heavy vehicle fleet.

Acknowledgements

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1 Introduction

The aim of this project was to demonstrate the effectiveness and characterise the performance of electronic stability aids on Performance Based Standards (PBS) combination vehicles, in particular, trailer electronic braking systems with rollover stability control (RSC). These systems are now compulsory under ADR 35/06 for prime movers, but not for entire combinations. The PBS scheme does not require the fitment of these systems other than to the extent required under the ADRs, although fitment can be required, at the discretion of vehicle assessors, as a condition of vehicle approval. It is intended that this project will support the adoption of a requirement for stability systems on PBS vehicles as an addition to the scheme rules. This change would enable PBS vehicles to continue to be the safest vehicles on Australian roads, through having trailers and dollies fitted with advanced stability technology.

This project involved field testing and in-service testing to measure the effects of stability systems on PBS A-double vehicle during both a PBS lane change test manoeuvre and their normal operation on the road network. It is anticipated that the outputs of the testing will show that the systems improve the stability of long combinations and do not introduce adverse safety effects. From the analysis of the test outputs, recommendations will be made for inclusion of a stability system requirement on PBS vehicles. The testing program is expected to produce the critical information on how these technologies perform during PBS-style manoeuvres and therefore address this knowledge gap which has up until now prevented advanced safety technologies from being included in the PBS scheme. The timing of project is such that it can inform the review of the PBS standards.

1.1 Project objectives

The objectives of this project were to:

- Demonstrate the effectiveness and characterise the performance of trailer electronic braking systems with RSC on PBS combination vehicles.
- Quantify the influence of these stability systems on vehicle dynamics during high-speed manoeuvres, specifically PBS lane change tests, and under normal in-service operating conditions.
- Generate data and insights that support the inclusion of stability system requirements in the PBS scheme rules, ensuring PBS vehicles continue to lead in safety performance on Australian roads.

1.2 Expected outcomes

The expected outcomes highlight the practical benefits of RSC to industry knowledge and future policy development, including the following:

- A comprehensive dataset and analysis showing how RSC systems improve vehicle stability, reduce rearward amplification, during a PBS lane change manoeuvre.
- Evidence from both in-service monitoring and controlled field testing that demonstrates the benefits and practical operation of these systems on PBS A-double combinations.
- Insights into the frequency of system interventions and faults in real-world operations, informing future policy options for in-service compliance requirements.
- A technical basis for policy recommendations to integrate mandatory stability systems into the PBS assessment framework and to explore mechanisms for ongoing operational compliance.

2 Method

The project comprised two distinct stages:

- Stage 1 – In-service data monitoring
- Stage 2 – Field testing program.

The aim and method for each stage is outlined in the following sections.

2.1 Stage 1 – In-service data monitoring

The aim of Stage 1: In-service data monitoring was to gain a better understanding the performance of the vehicles fitted with RCS. This was to be achieved by either fitting sensors to a fleet of vehicles or accessing data from an EBS module with RCS activated. The NTRO contacted a number of transport operators, and successfully identified a large fleet of over 240 trailers that included PBS A-doubles.

This stage of the project was able to successfully demonstration the in-field compliance and the intervention levels of vehicles as they operated on their normal routes. The intention of this part of project is to use the level of compliance and interventions observed in the field to inform any potential conditional network access requirements and the need or their performance to be reported during operation to ensure safe operation.

The NTRO reached out to a number of transport operators to assist with this stage. A transport operator gave permission to the NTRO to access their trailer telematics data for the purpose of this project. Data was collected for a period of 24 months; this data was sufficient to quantify the performance of the fleet. The data collected was summarised using the following metrics:

- Number of trips
- Number of kms
- Number of kms/laden
- Number of hours
- Number of RCS interventions
- RCS intervention type: low speed/ high speed
- RCS intervention type: small radius curve/ large radius curve/ intersection/ straight
- RCS intervention type: rural/urban
- System faults: All with the same categorisation.

This study was important to inform future policy regarding in-service requirements in particular.

1. Number of interventions, i.e. a high occurrence of rollover interventions which would indicate a high reliance on the stability system to prevent rollover.
2. Leve of compliance, i.e. the percentage of units that had system faults that prevented partial or full functionality.

2.1.1 Vehicle fleet

The vehicle fleet opted to share data on the basis that it was reported anonymously in aggregated form. The fleet comprised over 240 trailers including PBS A-doubles.

2.1.2 Data collection

In-service data was collected with the assistance of Air Brake Systems who are electronic braking and data service providers to the transport industry. The data was collected via an application programming interface (API) and via a physical download of the data via the operating data recorder (ODR) report.

2.1.3 Telematics data analysis

Over the 24-month period, more than 200 RSC interventions were recorded. While it is well established that RSC is highly effective at preventing rollovers, this data alone does not indicate whether this represents a high or low frequency of interventions. However, it does confirm that the systems are active and frequently engaged during normal operations, highlighting their real-world effectiveness in mitigating rollover risks that might otherwise go unmanaged.

In addition to RSC interventions, the dataset also captured system faults in the form of “red alerts” and “amber warnings.” A red alert renders the system non-functional and typically indicates issues such as low voltage, coupling failures (e.g., disconnected or broken pin). Amber warnings, often due to temporary conditions like low air pressure, also deactivate the RSC but are generally short-lived. The high number of faults relative to interventions indicates that, while RSC is an effective rollover prevention technology, maintaining system reliability is critical to ensure it functions when needed. Addressing the underlying causes of faults and warnings will be essential if RSC is to be included in PBS and to fully realise its safety benefits. Solutions that help ensure the system remains operational in service, such as real-time status updates or indicator lights on the trailer or dashboard to alert operators to faults, are options that could support this.

A detailed analysis of this in-service data was beyond the scope of this HVSI project. However, the dataset is rich and would benefit from a more comprehensive review. If further work is undertaken, it would be valuable to capture more context around each intervention, including the specific vehicle, location, road type, curve radius, speed limit, and actual vehicle speed. This analysis could clarify how many interventions are attributable to A-doubles, and specifically PBS A-doubles, which are the primary focus of this project. It would also provide useful insights into the types of situations where interventions occur, such as low-speed tight-radius turns or high-speed curves.

2.2 Stage 2 – Field testing program

Stage 2 of the project was to undertake a field-testing program of a road train representative of PBS A-doubles to quantify its performance during a PBS lane change manoeuvre. The field test component of this project will require substantial resources and the coordination of input from several parties. Stage 2 included the completion of the following tasks:

Test Preparation

- Test design and venue
- Subject vehicle
- Measurement equipment and vehicle sensors.

Test Program

- Vehicle instrumentation and logging data
- High-speed tests
- Data analysis.

2.2.1 Test design and venue

Safety was the priority of the test design and venue selection. The PBS standard requires that the lane change manoeuvre be conducted at 88 km/h; however, to mitigate risks the test program was designed to begin at lower speeds, with speed increasing on successive runs and carried out at 88 km/h only if deemed safe to do so. Prior to testing, the NTRO completed a safe work method statement (SWMS) for the testing program. The SWMS has not been included in this technical report but can be provided upon request. Further assessments to determine the risk and merits of testing at the threshold speed were made with the vehicle operator, RCS manufacturer, NHVR representatives.

TEST REQUIREMENTS

The requirements of the test that influenced its final design, vehicle and venue selection are listed below:

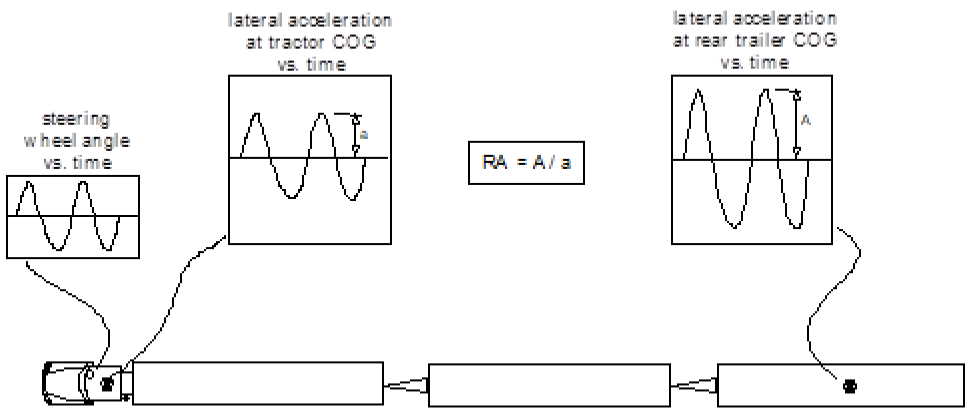
- Test speed of 88 km/h
- Closed road or controlled environment to reduce interaction with traffic
- Both vehicle units must be fitted without riggers
- Minimum road width as required for lane change with outriggers
- Tests to be completed with various states of RCS functionality
- Tests to be completed with trailers fully loaded
- Tests to be completed at multiple CoG heights (covering a range determined by a study of typical PBS A-double combinations).

TEST MANOEUVRE

The functionality of the EBS system with RCS will be evaluated using the PBS lane change manoeuvre.

The PBS lane-change manoeuvre is the method used to measure the rearward amplification (RA) and high-speed transient off-tracking (HSTO) of a vehicle combination. The intention of the lane-change manoeuvre is to produce a known lateral acceleration at the steer axle, at a given frequency, and to record the lateral acceleration experienced at the rear unit. The ratio of peak lateral acceleration at the rear unit to that at the steer axle is the RA of the vehicle (Figure 2.1).

Figure 2.1: Determination of rearward amplification



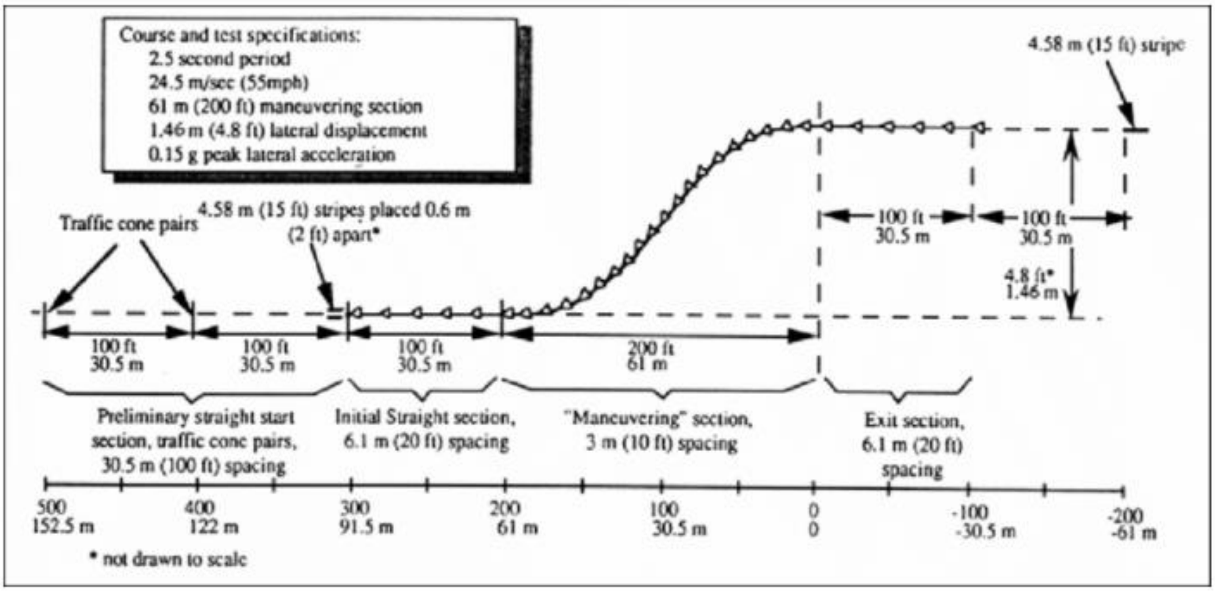
Source: NTRO

RA generally pertains to heavy vehicles with more than one articulation point, such as truck-trailers and road train combinations. RA describes the tendency for the trailing unit(s) to experience higher levels of lateral acceleration than the hauling unit during a dynamic manoeuvre. It is a serious safety issue in rapid path-change manoeuvres as it can lead to rear-trailer rollover.

Each unit in the combination amplifies the lateral acceleration of the unit immediately ahead of it, and thus amplification of lateral acceleration increases toward the rear of the vehicle. Lower values of RA indicate better performance. Higher values of RA imply higher probabilities of rear-trailer rollover. The RA requirement for all PBS vehicles is no greater than 5.7 times the static rollover threshold of the rearmost unit or roll-coupled set of units taking account of the stabilising influence of the roll coupling.

The path the driver is required to take will be marked on a flat and even section of road with minimal cross-slope, as outlined in the figure below. The dimensions of the test path are described in ISO14791:2000 and shown in Figure 2.2.

Figure 2.2: Lane change layout as per ISO14791:2000

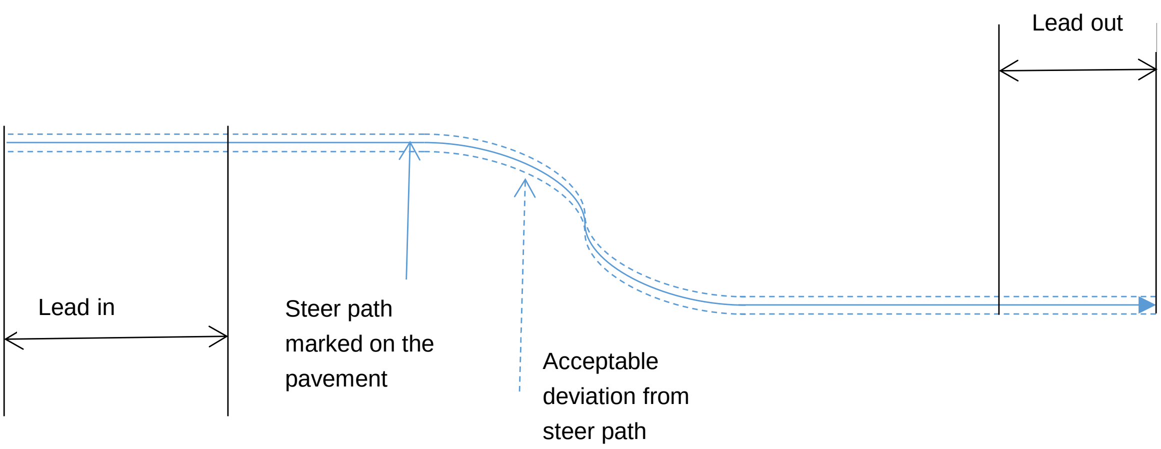


Source: ISO14791:2000

The following the lane change steer path is critical to ensure that the correct lateral acceleration at the steer axle, at a given frequency, is generated. Due to the technical difficulty of following an exact path without the aid of an automated vehicle, the manoeuvre will not be a lane change manoeuvre in accordance with PBS requirements. However, the aim will be to generate sufficient lateral acceleration at the rear of the vehicle, as a proportion of steer axle acceleration input, approximate the aim of the test. It is also intended that the manoeuvre will cause the RCS to intervene and maintain vehicle stability during lateral movement.

To be certain that the driver followed the path within the acceptable tolerance a camera was mounted to the front of the vehicle to record the position of the steer tyre relative to the markers.

Figure 2.3: Lane change steer path and tolerance



Source: Adapted from ISO14791:2000

VENUE

Conducting a high-speed lane-change test with a long combination vehicle necessitated the use of a length of road sufficient for the vehicle to accelerate, perform the test, stop safely or continue safely before turning around to return and repeat the test. The roadway will also need to accommodate the full width of the test vehicle with its outrigger axles fitted, and to allow the lateral movement of the lane-change manoeuvre. The road surface must also be sealed and within the road geometry (alignment, roughness, crossfall and grade) tolerances of the test standard. The SWMS also required that the tests be conducted in a controlled environment.

The project team reviewed suitable test venues within Australia, including vehicle testing and training facilities and airport runways. Two venues were selected: 1) Wodonga TAFE, Driving Education Centre of Australia (DECA), Shepparton shown in Figure 2.4 and Figure 2.6 and 2) Australian Automotive Research Centre, Wensleydale, Victoria shown in Figure 2.5 and Figure 2.7.

Figure 2.4: Venue 1 – DECA test facility used for vehicle instrumentation and low-speed testing

Source: Wodonga TAFE

Figure 2.5: Venue 2 – AARC test facility used for high-speed testing

Source: Australian Automotive Research Centre

Figure 2.6: Venue 1 – DECA test facility skid pan and test circuit

Source: Nearmap

Figure 2.7: Venue 2 – AARC highway circuit

Source: Australian Automotive Research Centre

2.2.2 Subject vehicle

The subject vehicle was a combination vehicle that was representative of a PBS A-double but also satisfied the requirements of the test design which included:

- ability to de-activate the EBS systems on each vehicle unit
- ability to fit out-rigger on each vehicle unit
- ability to adjust the CoG height on each vehicle unit
- able to record data on the activation of the EBS systems on each vehicle unit.

The subject vehicle selected for testing is shown in Figure 2.8. The combination comprised a Kenworth prime mover hauling a specialist A-double trailer set from Knorr-Bremse used. The lead trailer was fitted with hydraulically controlled out-riggers and weights allowing for CoG height adjustment. The rear trailer was fitted with a container with a mezzanine floor that allowed for test weights to be positioned on the upper or lower decks.

Figure 2.8: Subject vehicle at DECA test circuit

Source: A.Germanchev (NTRO)

The subject vehicle was tested at axle weights shown in Table 2.1.

Table 2.1: Test vehicle axle weights

Steer	Drive	Lead Trailer	Dolly	Tag Trailer	Total
6,348 kg	15,904 kg	19426 kg	16,141 kg	16,171 kg	**73,990 kg**

The details for the subject vehicle tyres, suspensions and axles are shown in Table 2.2.

Table 2.2: Subject vehicle tyres, suspensions, axles

Parameter	Prime mover		Lead trailer	Tag trailers	Dolly
	Steer	Drive			
Tyre data					
Tyres	295/80R22.5	11R22.5	11R22.5		
Type	Kenworth leaf spring	Air	Leaf		
Axles					
Axle track widths	2.02 m	1.82 m	1.84 m		
Dual tyre spacing	0.34 m				

The subject vehicle was tested at two centre of gravity (CoG) heights. The two CoG heights were selected based on a review of PBS assessments conducted by NTRO/O'Brien Traffic, with the aim of representing a PBS A-double with a low CoG and one with a high CoG.

The review of recently assessed PBS A-doubles included the following combinations:

- Tanker (Dangerous Goods) A-double at 91 t GCM with tri-axle dolly:
  - 2.155 m front roll-coupled unit (RCU) and 2.21 m rear RCU (sprung mass only),
  - 1.83 m front RCU and 1.98 m rear RCU (sprung and unsprung mass).
- Container A-double at 85.5 t with tandem dolly
  - 2.42 m front RCU and 2.29 m rear RCU (sprung mass only),
  - 1.99 m front RCU and 2.06 m rear RCU (sprung and unsprung mass)
- Tipper A-double at 91 t with tri-axle dolly,
  - 2.255 m front RCU and 2.1 m rear RCU (sprung mass only),
  - 1.89 m front RCU and 1.89 m rear RCU (sprung and unsprung mass).

Based on this data the CoG heights were selected for the 'low' and 'high' test options. The CoG heights for the subject vehicle as tested are shown in Table 2.3

Table 2.3: CoG Heights (m)

Vehicle unit	Low	High
Lead Trailer	1.86m	2.25m
Tag Trailer	1.93m	2.25m

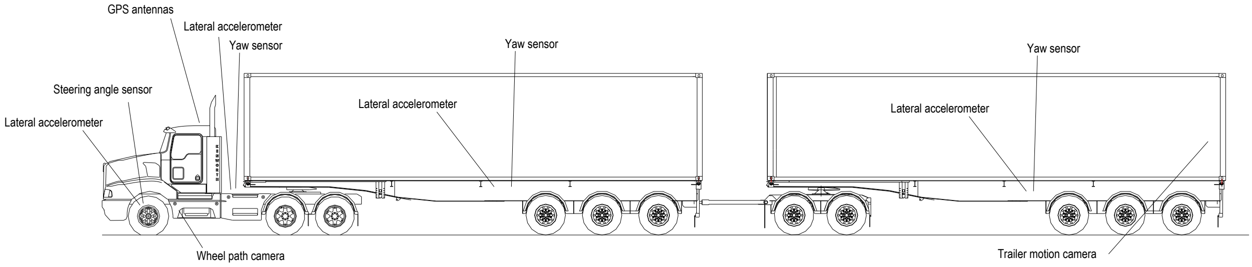
The rear trailer was fitted with out-riggers that could be removed for transit. The vehicle units were assembled in its test configuration for system set-up and configuration at the DECA facility and AARC facility. The vehicle units separately between facilities.

2.2.3 Measurement equipment and vehicle sensors

The following sensors and equipment were fitted to the test vehicle (in positions shown in Figure 2.9):

- a high-speed global positioning system (GPS) device measuring vehicle position and speed.
- 3 x inertial measurement units (IMU) fitted to the prime mover, and first and second trailer bodies, each IMU contained the following sensors:
  - tri-directional accelerometers measuring the acceleration in the X, Y and Z directions.
  - yaw sensors, measuring the yaw rate of the prime mover body, and two trailer bodies.
- two camera units, both synchronised to the data, that record video of the trailer body motions, and the level to which the prime mover’s steer tyre matches the prescribed path.

Figure 2.9: Approximate layout of vehicle sensors for A-double road train configuration



Source: NTRO

The test vehicle during set-up at AARC is shown in Figure 2.10.

Figure 2.10: Test vehicle prior to testing

Source: A.Germanchev (NTRO)

3 Test Program

The field test program was conducted in two stages over two separate weeks. The purpose of the first stage was to ensure the vehicle sensors were fitted correctly and calibrated for the high-speed tests conducted as part of stage2. Stage 1 was conducted at DECA, Shepparton in the week starting 18 March 2024. Stage 2 was conducted at AARC, Wensleydale in the week starting 25 March.

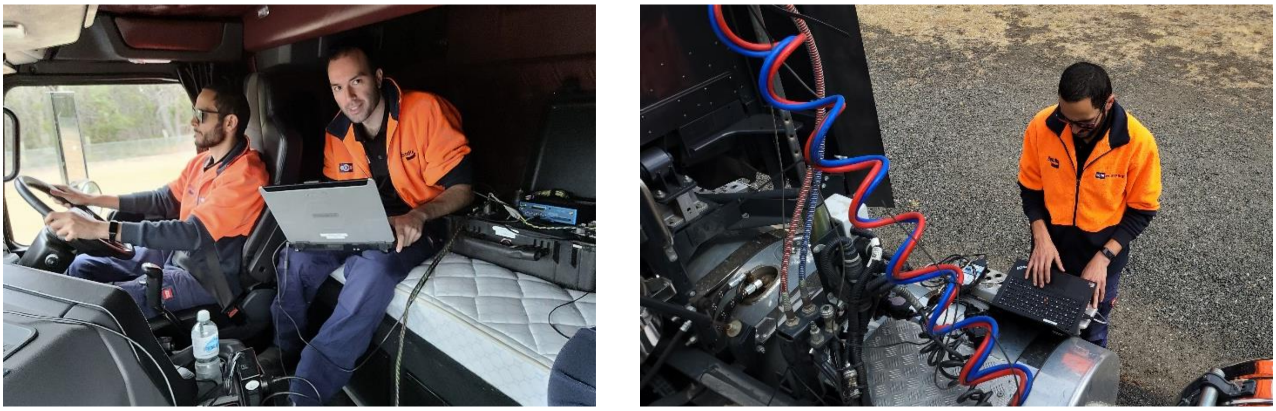
The aim of the Stage 2 test program was to demonstrate the effectiveness of RCS during a PBS lane change manoeuvre and record the data necessary to establish a relationship between speed, lateral acceleration and triggering of an RSC intervention.

3.1 Instrumentation and data acquisition

The instrumentation fitted to the Knorr-Bremse test vehicle included the data acquisition system fitted to the Knorr-Bremse trailer and additional sensors fitted by NTRO.

Figure 3.1 shows the field engineers fitting sensors and configuring data acquisition system.

Figure 3.1: Field engineers fitting sensors and configuring data acquisition system



Source: A.Germanchev (NTRO)

Figure 3.2 shows the NHVR engineering team measuring the vehicle and recording the dimensions for the purpose of modelling the vehicle and simulating its performance.

Figure 3.2: NHVR staff measuring the test vehicle

Source: A.Germanchev (NTRO)

Figure 3.3 shows an example of one of the vehicle sensors fitted to the vehicle during the instrumentation and set up prior to testing.

Figure 3.3: Vehicle sensor (IMU) positioned on prime mover cross member

Source: A.Germanchev (NTRO)

3.2 PBS Lane change manoeuvre

The high-speed tests were conducted using the PBS Lane Change manoeuvre. The path the driver is required to take will be marked on a flat and even section of road with minimal cross-slope, as shown in Figure 3.4. The dimensions of the test path are described in ISO14791:2000.

Figure 3.4: Lane change path as marked for testing on AARC highway circuit

Source: A.Germanchev (NTRO)

The tests were conducted on the highway circuit of the AARC vehicle proving grounds. This circuit provided sufficient distance for the vehicle to accelerate to the required test speeds in the lead-in section, then execute the manoeuvre. The lateral acceleration, speed measurements, and vehicle position were recorded for each run. A video camera was also used to monitor vehicle performance.

The aim of the test manoeuvre was to generate sufficient lateral acceleration at the rear of the vehicle, as a proportion of steer axle acceleration input, and cause the RCS to intervene and maintain vehicle stability.

3.3 Test schedule

The test schedule show in Table 3.1 listed the tests in order. The order was based on a risk assessment with the lowest risk tests to be conducted first, which was the low CoG height configuration at low speed.

Table 3.1: Testing schedule

Test	COG Height	Speed	EBS	Notes/Description
-	Low			Check lane change position, track familiarisation
-	Low	80 km/h		Tests at low speeds (40 – 80 km/h)
1	Low	88 km/h	ALL ON	-
2	Low	88 km/h	ALL ON	-
3	Low	88 km/h	ALL ON	Check data – repeat if needed
4	Low	88 km/h	ALL OFF	-
5	Low	88 km/h	ALL OFF	-
6	Low	88 km/h	ALL OFF	Check data – repeat if needed-
7	Low	88 km/h	ON/OFF/ON	-
8	Low	88 km/h	ON/OFF/ON	-
9	Low	88 km/h	ON/OFF/ON	Check data – repeat if needed-
10	High	88 km/h	ALL ON	-
11	High	88 km/h	ALL ON	-
12	High	88 km/h	ALL ON	-
13	High	88 km/h	ALL OFF	-
14	High	88 km/h	ALL OFF	-
15	High	88 km/h	ALL OFF	-
16	High	88 km/h	ON/OFF/ON	-
17	High	88 km/h	ON/OFF/ON	-
18	High	88 km/h	ON/OFF/ON	Check data – repeat if needed -
				End of test remove equipment

The test procedure described in ISO 14791:2000(E) sections 7.1, 7.2, 7.3 and 7.5 (single lane-change) were used as a guide for the testing. The manoeuvre was planned to provide a peak lateral acceleration of 0.15 g and a steer frequency equal to 0.40 Hz at a vehicle speed of 88 km/h. Although the PBS rules advised against performing the lane change test if the response of the last unit is likely to exceed 75% of the estimated rollover limit or 75% of any tyre friction limit unless suitable safety mechanisms are in place. Trial runs at lower severity (e.g. lower speed) are encouraged to predict the ability of the vehicle to safely complete the manoeuvre.

Figure 3.5 shows the CoG height of the lead trailer being adjusted from the low position to the high position. The lead trailer is fitted with a payload system that can be adjusted hydraulically allowing for incremental changes to be made quickly.

Figure 3.5: CoG height of the lead trailer being adjusted during testing

Source: A.Germanchev (NTRO)

Figure 3.6 shows the CoG height of the rear trailer being adjusted using a loader to relocate the load from the lower deck to the upper deck. The load was then secured using straps.

Figure 3.6: CoG height of the rear trailer being adjusted during testing

Source: A.Germanchev (NTRO)

4 Data analysis

A total of 64 tests were performed to quantify the performance of the RCS during high-speed manoeuvres. All test data was processed and were analysed. The tests were reviewed for compliance with the lane change requirements including the entry and exit speeds and steering path. A selection of tests that were within the acceptable tolerances were selected for further analysis. A summary of the test results for lateral acceleration for the low COG configuration is listed in Table 4.1. The results shown in parentheses are based on the filtered dataset that was not available until post processing had been completed. The subsequent tables only show results based on the filtered dataset.

Table 4.1: Summary of tests for low CoG configuration (NTRO data logging)

No.	Test ID	Entry speed (km/h)	Exit speed (km/h)	Speed Diff. (km/h)	Lat. Acc AY1 (g)	Lat. Acc AY3 (g)	RA	EBS
1	X0019	88.4	85.4	-3.0	0.389 (0.307)	0.489 (0.434)	1.28 (1.45)	ALL ON
2	X0020	88.8	84.9	-3.9	0.361 (0.297)	0.464 (0.431)	1.29 (1.45)	ALL ON
3	X0021	88.4	84.5	-3.9	0.302 (0.298)	0.461 (0.439)	1.53 (1.47)	ALL ON
4	X0032	88.7	85.8	-2.9	0.324 (0.245)	0.387 (0.371)	1.19 (1.51)	ON/OFF/ON
5	X0033	88.0	84.9	-3.1	0.376 (0.300)	0.381 (0.363)	1.01 (1.21)	ON/OFF/ON
6	X0034	88.2	84.7	-3.5	0.287 (0.258)	0.435 (0.410)	1.52 (1.59)	ON/OFF/ON
7	X0041	88.5	88.5	-0	0.280 (0.192)	0.312 0.304	1.11 (1.58)	ALL OFF
8	X0042	88.8	88.6	-0.2	0.257 (0.217)	0.524 (0.477)	2.04 (2.20)	ALL OFF
9	X0043	88.8	88.6	-0.2	0.254 (0.232)	0.479 (0.405)	1.89 (1.75)	ALL OFF

A summary of the test results for lateral acceleration for the high COG configuration is listed in Table 4.2.

Table 4.2: Summary of tests for high CoG configuration (NTRO data logging)

No.	Test ID	Entry speed (km/h)	Exit speed (km/h)	Speed Diff. (km/h)	Lat. Acc AY1 (g)	Lat. Acc AY3 (g)	RA	CoG Height	EBS
10	X0049	88.4	85.5	3.0	0.220	0.377	1.71	High	ALL ON
11	X0050	88.6	86.0	2.6	0.221	0.418	1.89	High	ALL ON
12	X0051	88.6	85.6	3.0	0.248	0.402	1.62	High	ALL ON
13	X0062	89.2	86.7	2.5	0.327	0.419	1.28	High	ON/OFF/ON
14	X0063	88.8	86.5	2.3	0.327	0.394	1.21	High	ON/OFF/ON
15	X0064	88.8	86.9	1.9	0.267	0.437	1.64	High	ON/OFF/ON
16	X0075	88.4	88.2	0.2	0.317	0.429	1.35	High	ALL OFF
17	X0076	88.5	88.2	0.3	0.194	0.416	2.14	High	ALL OFF
18	X0078	88.5	88.3	0.2	0.324	0.471	1.45	High	ALL OFF

In addition to lateral acceleration and RA, other performance metrics were also monitored, including yaw rate and body roll. While yaw rate, for example, is typically used to assess yaw damping under a different PBS measure, these metrics are valuable for understanding the overall stability of the vehicle and the impact of RSC. A summary of these performance metrics is provided below Table 4.3.

Table 4.3: Summary of tests for high CoG configuration (NTRO data logging)

No.	Test ID	Yaw rate (+ve)	Yaw rate (-ve)	Delta	Roll rate (+ve)	Roll rate (-ve)	Delta	CoG Height	EBS
10	X0049	7.1	-10.5	-17.6	11.4	-10.8	-22.2	High	ALL ON
11	X0050	8.4	-12.2	-20.6	12.4	-15.3	-27.7	High	ALL ON
12	X0051	5.6	-8.4	-14.0	10.2	-8.6	-18.7	High	ALL ON
13	X0062	8.7	-11.9	-20.6	10.7	-12.8	-23.5	High	ON/OFF/ON
14	X0063	7.6	-10.6	-18.3	9.8	-11.0	-20.8	High	ON/OFF/ON
15	X0064	8.0	-11.8	-19.9	11.3	-13.4	-24.8	High	ON/OFF/ON
16	X0075	10.5	-11.9	-22.4	10.3	-16.6	-26.8	High	ALL OFF
17	X0076	8.6	-10.4	-19.0	12.7	-12.9	-25.6	High	ALL OFF
18	X0078	8.6	-11.0	-19.7	10.8	-12.9	-23.7	High	ALL OFF

The findings and conclusions from these test results are presented in the following sections.

Figure 4.1 shows the test vehicle performing the lane change manoeuvre at 88 km/h at AARC test facility.

Figure 4.1: Test vehicle during testing on the highway circuit at AARC

Source: A.Germanchev (NTRO)

Figure 4.2 shows the NHVR engineering team during a safety briefing prior to undertaking the next stage of testing with the vehicle loaded in its high CoG configuration.

Figure 4.2: Safety briefing during testing

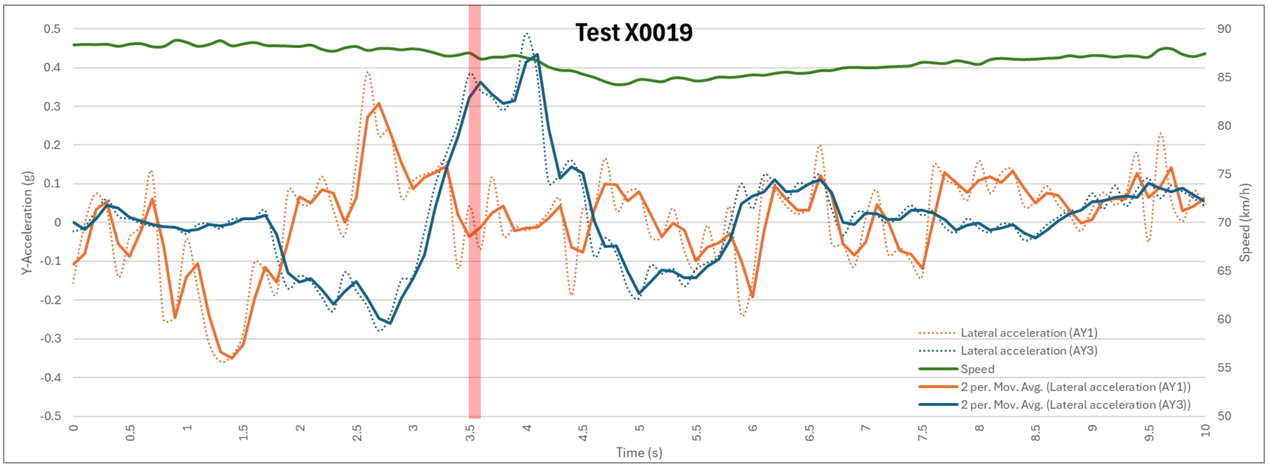
Source: A.Germanchev (NTRO)

4.1 Test results – acceleration

The charts included in this section of the report show the lateral acceleration recorded on the prime mover and the rear trailer.

Figure 4.3 shows the data trace for test X0019, this was test number 19 in the test program, and the first test identified for further analysis. The test was performed with the vehicle in its original configuration of low CoG and with EBS active on all trailer units. The chart shows the raw data for the prime mover as a dotted orange line, labelled lateral acceleration (AY1) and filtered data (moving average) as a bold solid orange line labelled 2 per. Mov. Avg. (lateral acceleration (AY1)). The chart shows raw and filtered data for the rear trailer in a similar format, but in dark blue. Also displayed on this chart is speed in km/h (shown on the secondary axis) and the time at which EBS system activated, shown as solid red vertical line.

Figure 4.3: Data trace for test X0019 – Low CoG and EBS on all trailer units



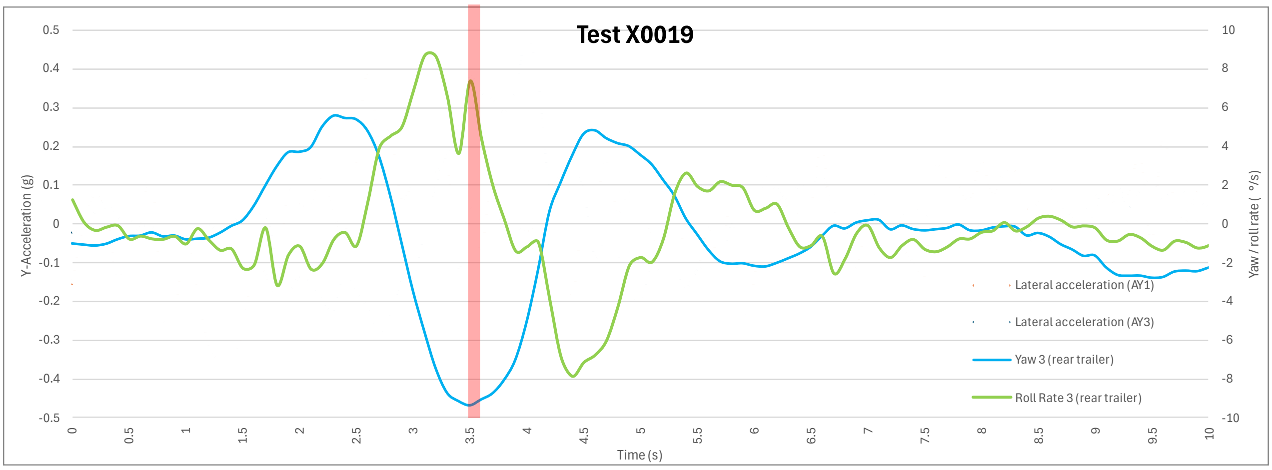
The data in Figure 4.3 shows that the peak lateral acceleration for the prime mover was over 0.3 g which is well above the required 0.15 g. The frequency of the input was 0.4 Hz, equivalent to the requirement and the entry speed was 88.4 km/h and the exit speed was 85.4 km/h. The reduction in speed was due to the EBS system activating during the manoeuvre. The total reduction in speed was 3.0 km/h approximately 3%. The rearward amplification for this manoeuvre was calculated to be 1.58.

A total of 3 tests for this vehicle configuration were analyse, in addition to test X0019 shown in, these test were tests X0020 and X0021 shown in Figure A.1.3 and Figure A.1.5 in Appendix A.

4.2 Test results – yaw and roll

Figure 4.4 shows the yaw rate (blue solid line) and roll rate (green solid line) for the rear trailer overlayed on the raw lateral acceleration for the prime mover and rear trailer with the rolling average removed.

Figure 4.4: Data trace for test X0019 – Low CoG and EBS on all trailer units (yaw rate)



This data was used to measure the performance of the A-double during the lane change and understand the effect that the activation of the RSC system had on the vehicles performance against the PBS standards. This was further explore by conducting vehicles simulations and comparing the results obtain from simulation with testing.

5 Comparison between testing and simulation

The performance of the test vehicle was assessed using simulation in accordance with the PBS Standards and Vehicle Assessment Rules. The PBS results from both the simulations and the physical testing are presented in Table 5.1. The simulation results indicate that the low centre of gravity (CoG) configuration meets all assessed PBS performance measures, while the high CoG configuration does not satisfy the Rearward Amplification (RA) requirement. The physical testing results show that the vehicle achieved satisfactory RA performance during the lane change manoeuvre when the EBS with Roll Stability Support (RCS) was active on all units, as well as when active on all units except the dolly. However, the vehicle did not meet the RA requirement when the RCS was inactive.

Table 5.1: Comparison of PBS performance results: testing versus simulation

Vehicle	Simulation						Testing		
	YDC (-)	TASP (m)	HSTO (m)	SRT1 (g)	SRT2 (g)	RA	RA (All ON)	RA (ON/OFF/ON)	RA (OFF)
Low CoG	**0.35**	**2.88**	**0.44**	**0.47**	**0.45**	**1.87**	**1.47**	**1.59**	**2.20**
PBS Level 2	0.15	3.0	0.8	0.35	0.35	2.57	2.57	2.57	2.57
Result	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS	PASS
High CoG	**0.26**	**2.93**	**0.56**	**0.36**	**0.35**	**2.0**	**1.89**	**1.64**	**2.14**
PBS Level 2	0.15	3.0	0.8	0.35	0.35	1.99	1.99	1.99	1.99
Result	PASS	PASS	PASS	PASS	PASS	**FAIL**	PASS	PASS	**FAIL**

*worst case results observed from valid tests

Based on these results, it can be concluded that roll stability control systems were effective in reducing the lateral acceleration experienced by the rear trailing unit, enabling a high centre of gravity A-double that failed RA in simulation to satisfy the PBS dynamic performance requirements for RA

6 Results

The results are summarised below and listed by key metric.

Entry and Exit Speeds

- Tests with "ALL-ON" or "ON/OFF/ON" EBS configurations experienced a deviation from the average speed ranging from 1.95 km/h to 0.95 km/h, less than the permitted maximum of 3 km/h proving that all tests were compliment with the PBS requirements.
- "ALL-OFF" EBS configurations had minimal speed differences (close to zero) as EBS was in-active and no braking occurred during these tests.

AY1 (Lateral Acceleration at the prime mover):

- The lateral acceleration generated at the prime mover ranged between 0.220–0.327, this suggests the lane change manoeuvre was more severe with a higher input than the 0.15 g required for PBS assessment. It should be noted that the location of the accelerometer was on the prime mover body not the steer axle.
- The AY1 values for the ON/OFF/ON and ALL-OFF configurations were higher in the high CoG tests (0.31g and 0.28g, respectively) compared to the low CoG tests (0.27g and 0.21g). However, this does not necessarily result in higher RA values, as the RA calculation incorporates a high denominator, offsetting the potentially greater lateral acceleration experienced by the rear trailer due to the increased input.

AY3 (Lateral Acceleration at the rear trailer):

- ALL-ON: On average AY3 was less in the high CoG test for the "ALL-ON" configuration (0.40 to 0.46g), suggesting that stability control effectively mitigated the peak lateral acceleration experienced by the rear trailer, even with a higher centre of gravity. This counterintuitive result is influenced by the fact that the high CoG tests had significantly lower input lateral accelerations, reducing the magnitude of forces acting on the rear axle.
- ON/OFF/ON: On average AY3 was higher in the high CoG tests (0.42g to 0.38g), showing that intermittent braking configurations result in greater lateral forces under high CoG conditions.
- ALL-OFF: The high CoG test in the ALL-OFF configuration experienced the highest peaks on average (0.39g), indicating higher lateral forces at the rear trailer, due to the higher centre of gravity.

RA (Rearward Amplification)

When comparing the RA results from the Low CoG tests, the findings are straightforward. Both the ALL-ON and ON/OFF/ON configurations produced similar RA values (1.46 and 1.44, respectively), which were significantly lower than the RA value of 1.84 observed for the ALL-OFF configuration. Proving that RSC effectively reduced the RA during the lane change manoeuvre.

For the High CoG tests, the RA results for the ALL-ON configuration were inconsistent with the ON/OFF/ON and ALL-OFF configurations. This discrepancy was primarily due to the ALL-ON tests having a lower AY1 input. However, when focusing on the ON/OFF/ON configuration—which was not influenced by a low AY1 input, the trend remained consistent. The RA value for ON/OFF/ON (1.38) was lower than the RA for ALL OFF (1.65), further highlighting the stability benefits of active EBS.

The testing demonstrated the critical role of EBS with RSC in maintaining vehicle stability and how this equates to an improved RA result during a PBS lane change manoeuvre.

The test results provided compelling evidence that the vehicle, which had previously failed PBS assessments when evaluated using computer simulations that did not account for the functionality of RCS, was able to achieve a PASS during physical testing with the RSC system active. This highlights the limitations of traditional simulation models in accurately reflecting the impact of advanced safety technologies and underscores the importance of incorporating such functionalities into future PBS assessment frameworks. By demonstrating the RCS's ability to enhance stability and mitigate rollover risk, this test showcases the potential for these systems to enable vehicles to meet stringent safety standards while maintaining high productivity.

6.1 Discussion

Overall, the project has provided evidence supporting the inclusion of roll stability system requirements for PBS vehicles. Through the demonstration of the safety benefits offered by ESC and RSC technologies, this project had provided the basis for future policy developments, which could be considered a part of the NHVR’s PBS 2.0 review of the PBS rules.

The project also provided insights into the on-road operation of these systems, highlighting the importance to implement a policy that considered the initial PBS assessment and approval of the vehicle but also a method for ensuring its in-service compliance.

Implementing these advanced safety technologies as a standard requirement in the PBS scheme will ensure that PBS vehicles continue to be the safest on Australian roads, ultimately contributing to a safer and more efficient road freight industry.

7 Conclusion

This project has successfully demonstrated the effectiveness and characterised the performance of electronic stability systems on long combination PBS combination vehicles. This was achieved through an approach that included both in-service data monitoring and field testing. The field-testing program demonstrated the functionality and benefits of these stability systems during a high-speed dynamic manoeuvre. The data collected during both stages of the project provided a basis for characterising the performance of electronic stability systems and for inclusion in the PBS assessment process.

Stage 1 of the project focused on in-service monitoring of A-doubles fitted with EBS and reported on the frequency and context of RCS interventions, along with system fault rates. The in-service data monitoring provided the evidence required to understand how these systems operate under normal driving conditions. This stage emphasized the importance of ensuring the compliance of stability systems when in-service, while highlighting their significant role in preventing rollovers and maintaining vehicle stability under various conditions including at low and high speeds. The collected data underscored the necessity for an in-service compliance standard to ensure the assessed safety performance is maintained when in operation on road.

The field-testing program conducted in Stage 2 of the project further validated these findings by quantifying the performance of a representative PBS A-double road train during a PBS lane change manoeuvre. The results confirmed that EBS with roll-stability control activate during this high-speed dynamic avoidance manoeuvre. These tests demonstrated unequivocally that roll-stability control improved the stability of the combination vehicle, without introducing any adverse safety effects.

Further tests were conducted to explore the limits of the vehicle's stability, these were done in separate tests with the EBS turned on and off. During these tests the manoeuvre was such that the rear trailer exceeded its rollover threshold, when the EBS was off, the rear trailer rolled onto the out-riggers preventing it from rolling over, when the EBS was on, the brakes were activated stabilising the rear trailer and preventing it from exceeding its roll threshold. The field testing was a world first demonstrating the effectiveness of the roll-stability during a high-speed PBS manoeuvre.

The project identified the following key learnings:

- EBS with RCS systems significantly reduced RA and maintained stability, preventing rollovers even in high-severity manoeuvres at high speeds.
- Fault rates were detected during in-service monitoring highlighting the importance of ensuring compliance during operation.
- The field testing underscored the importance of integrating EBS with RCS in PBS assessments to improve vehicle stability, whereas the operational data highlighted the need for in-service compliance standard that includes data monitoring.

7.1 Next steps

The data collected during this project remains with the NHVR and the Office of the Chief Engineer.

The next steps include:

- Development of policy recommendations to include the safety benefits of EBS with RCS systems in the PBS rules
- Development an in-service compliance requirement to address the fault rates detected during in-service monitoring.

References

ISO 14791:2000, Heavy commercial vehicles and buses — Assessment of stability by simulation, International Organization for Standardization, Geneva, 2000.

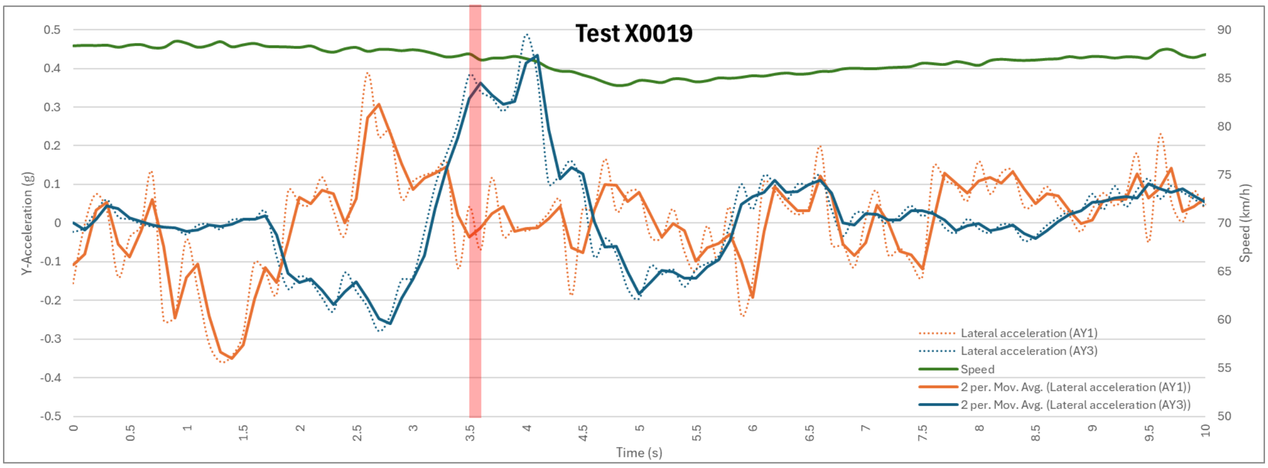
National Heavy Vehicle Regulator (NHVR). Performance Based Standards (PBS) Scheme: Standards and Vehicle Assessment Rules. Version current at November 2022, National Heavy Vehicle Regulator, Brisbane, Australia.

Appendix A Test results

A.1 Results for test 1 – 3: low CoG with EBS all ON

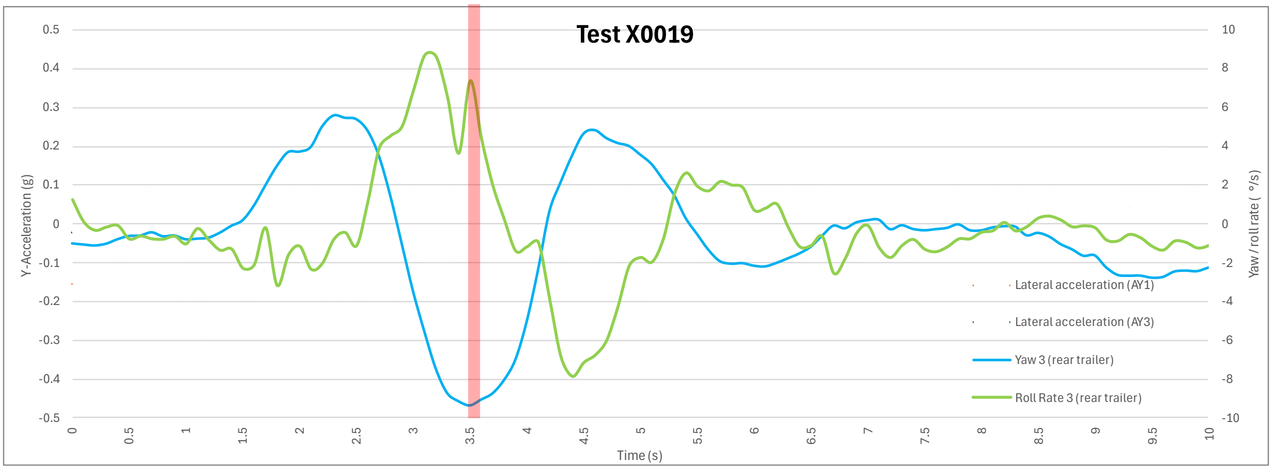
A.1.1 Test X0019 – lateral acceleration (EBS all ON)

Figure A.1: Data trace for X0019 - lateral acceleration (EBS all ON)



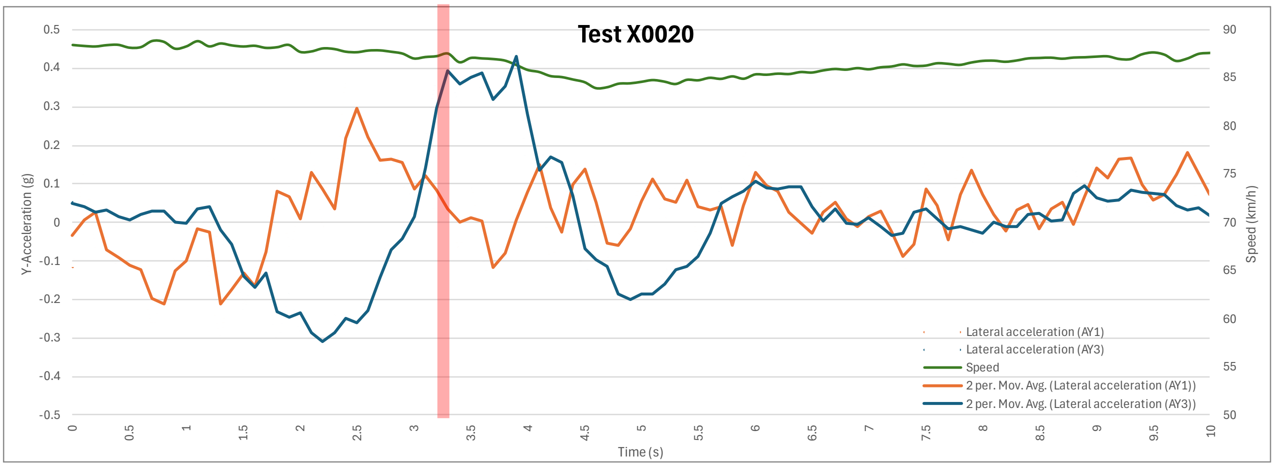
A.1.2 Test X0019 – yaw and roll rate (EBS all ON)

Figure A.2: Data trace for X0019 – yaw and roll rate (EBS all ON)



A.1.3 Test X0020 – lateral acceleration (EBS all ON)

Figure A.3: Data trace for test X0020 – lateral acceleration (EBS all ON)

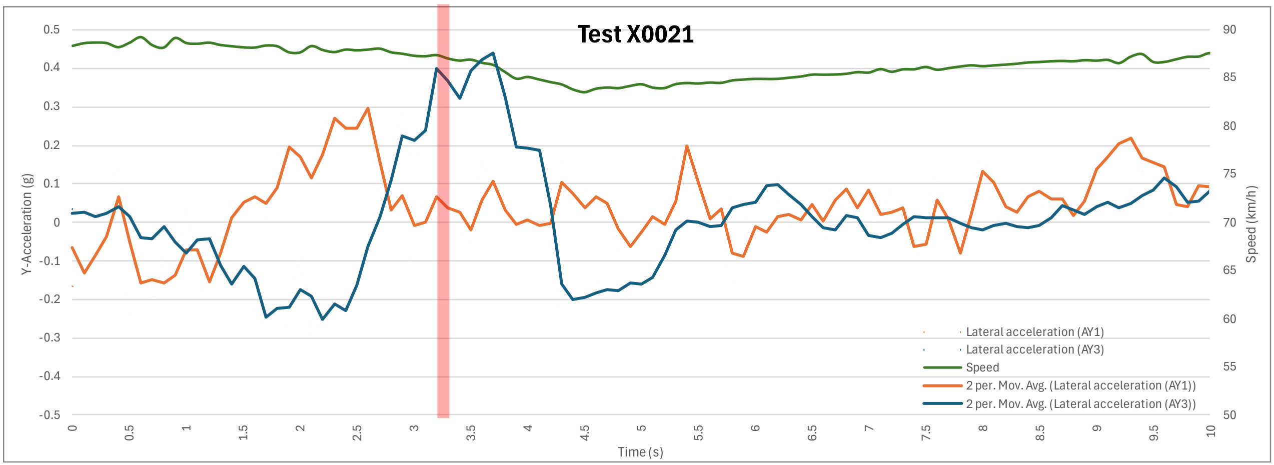


A.1.4 Test X0020 – yaw and roll rate (EBS all ON)

Figure A.4: Data trace for test X0020 – yaw and roll rate (EBS all ON)

A.1.5 Test X0021 – lateral acceleration

Figure A.5: Test X0021 – lateral acceleration (EBS all ON)



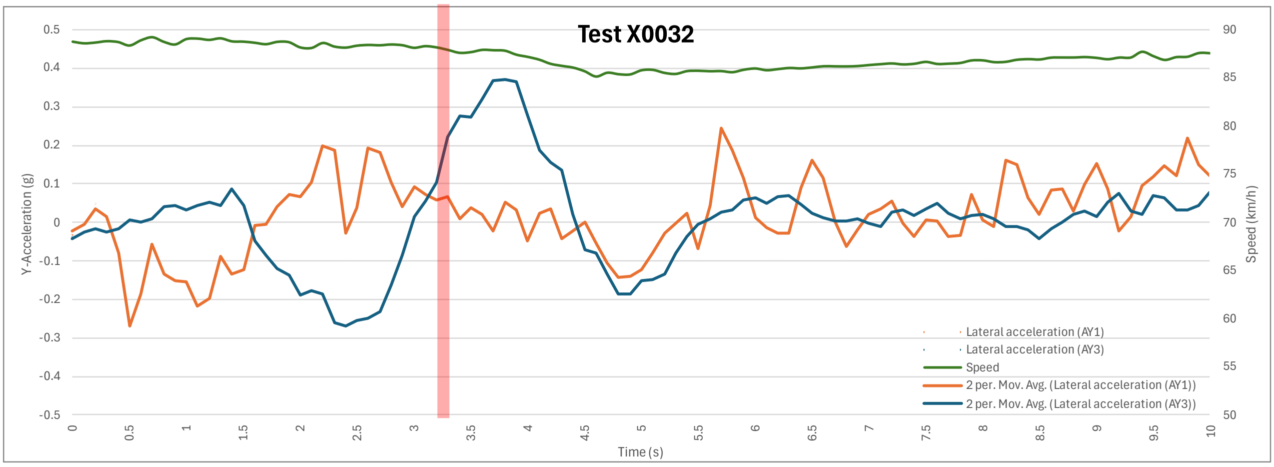
A.1.6 Test X0021 – roll and yaw rate

Figure A.6: Test X0021 – roll and yaw rate (EBS all ON)

A.2 Results for test 4 – 6: low CoG with EBS ON/OFF/ON

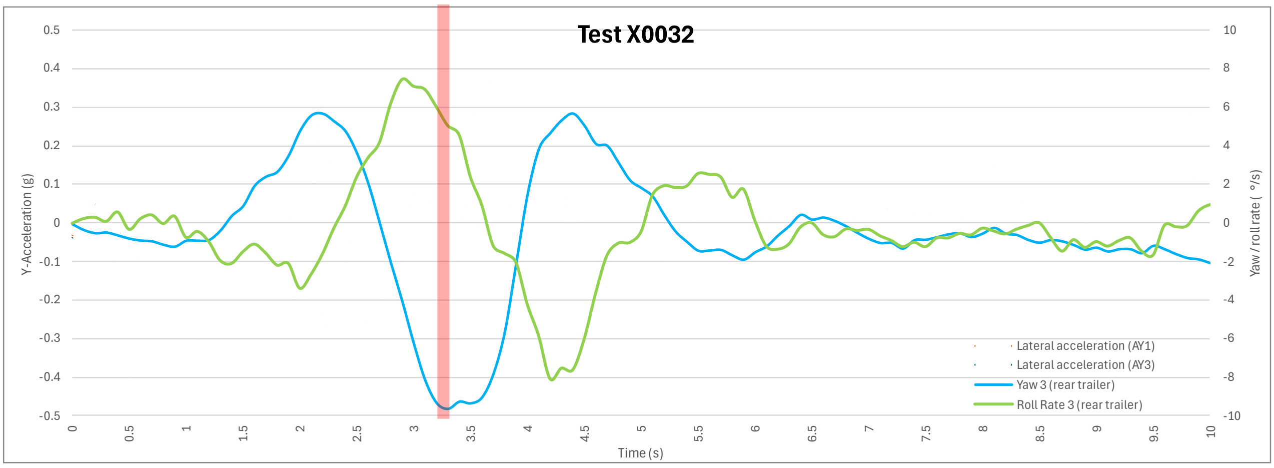
A.2.1 Test X0032 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

Figure A.7: Test X0032 – lateral acceleration (EBS ON/OFF/ON)



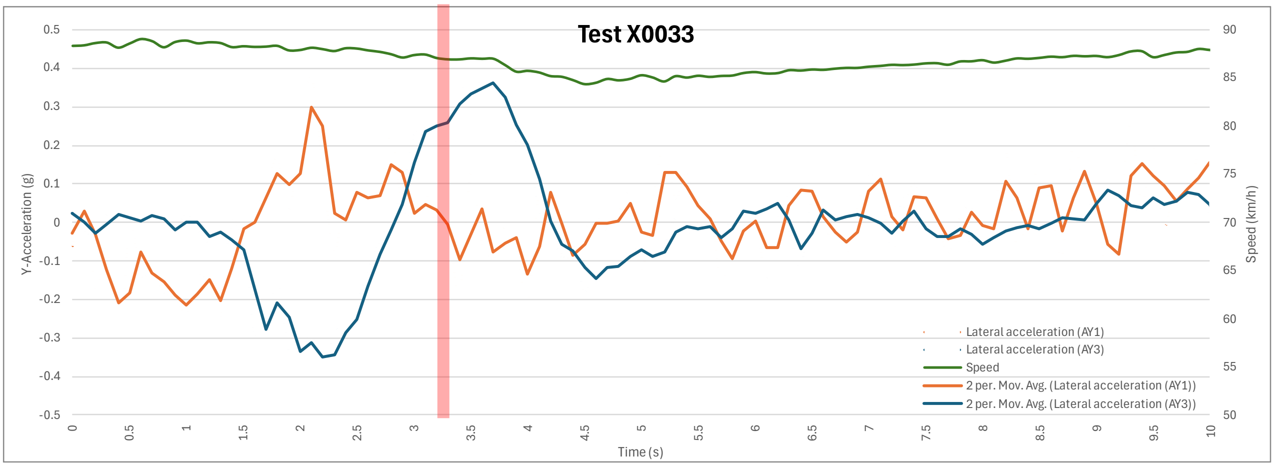
A.2.2 Test X0032 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

Figure A.8: Test X0032 – roll and yaw rate (EBS ON/OFF/ON)



A.2.3 Test X0033 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

Figure A.9: Test X0033 – lateral acceleration (EBS ON/OFF/ON)

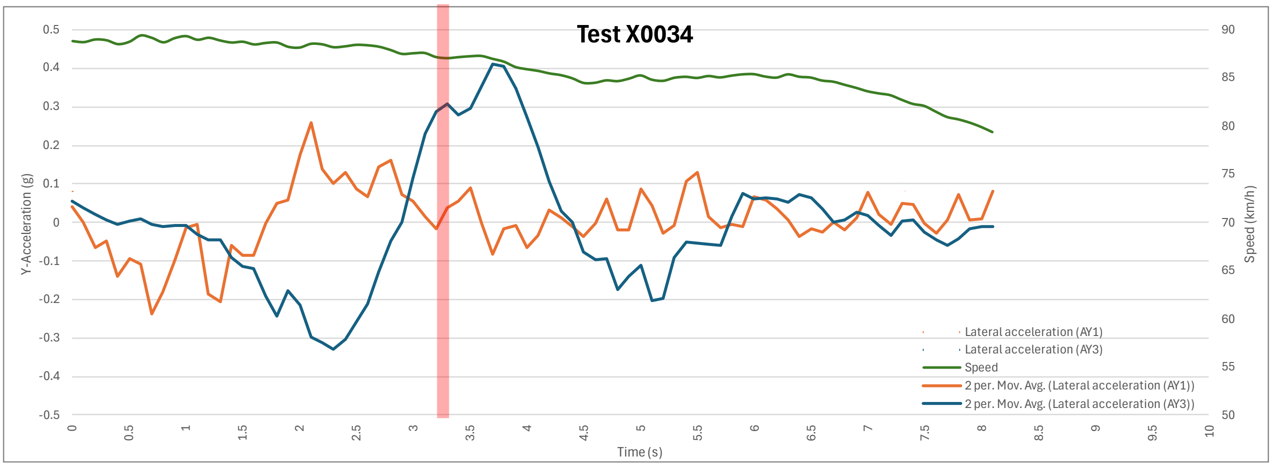


A.2.4 Test X0033 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

Figure A.10: Test X0033 – roll and yaw rate (EBS ON/OFF/ON)

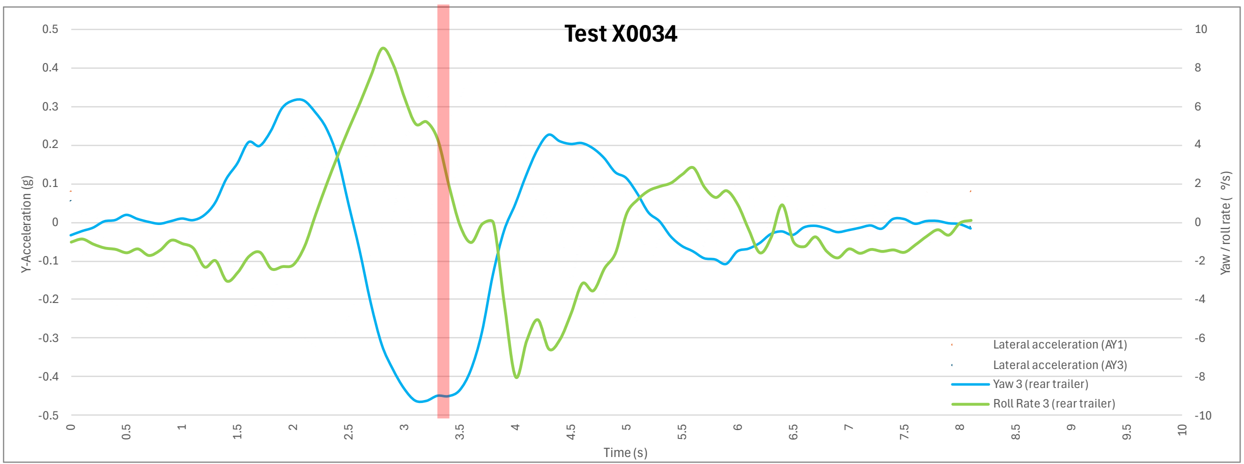
A.2.5 Test X0034 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

Figure A.11: Test X0034 – lateral acceleration (EBS ON/OFF/ON)



A.2.6 Test X0034 – Low CoG and EBS on lead trailer, off dolly, on rear trailer

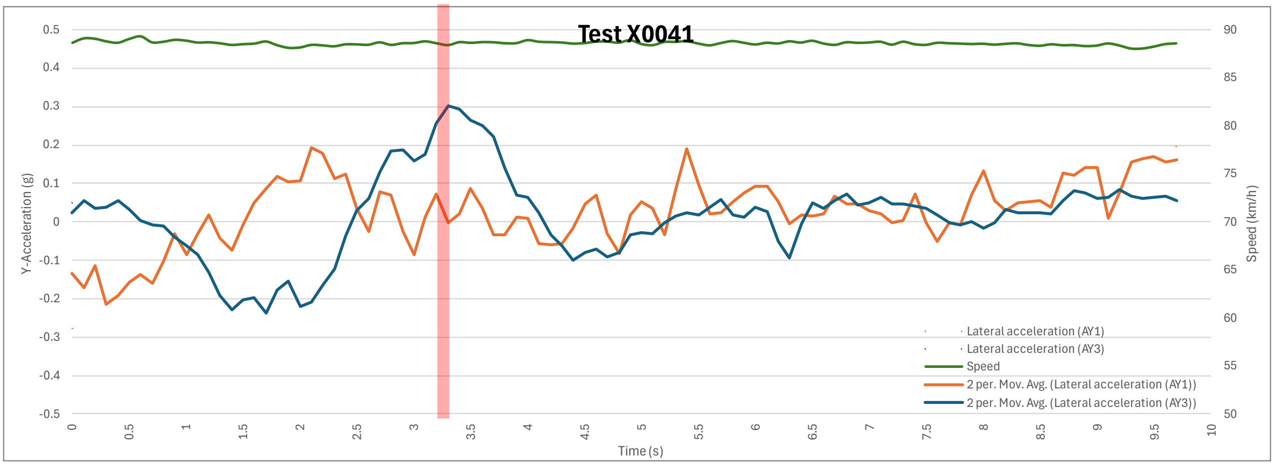
Figure A.12: Test X0034 – roll and yaw rate (EBS ON/OFF/ON)



A.3 Results for test 7 – 9: low CoG with EBS all OFF

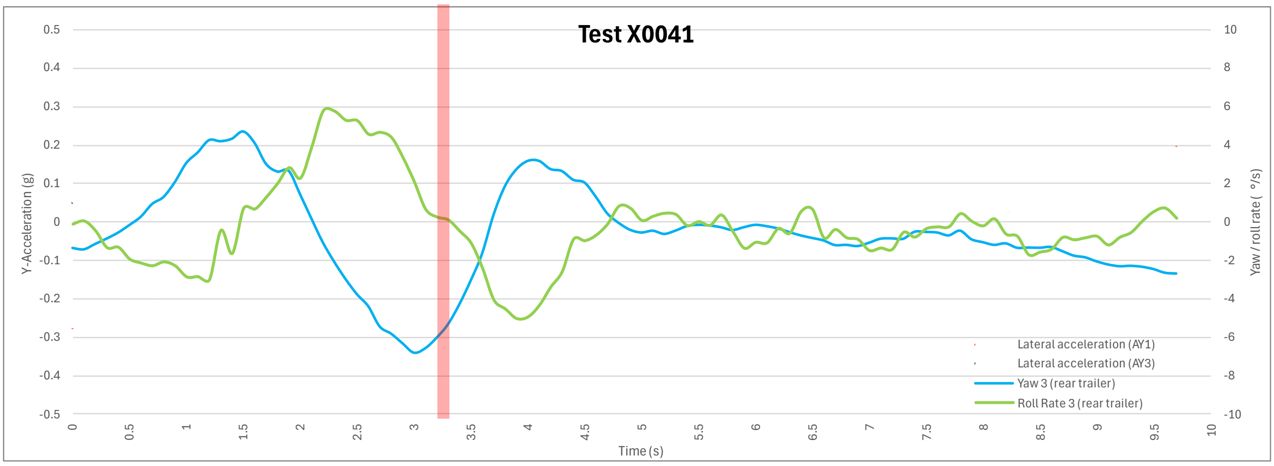
A.3.1 Test X0041 – Low CoG with EBS all OFF

Figure A.13: Test X0041 – lateral acceleration (EBS all OFF)



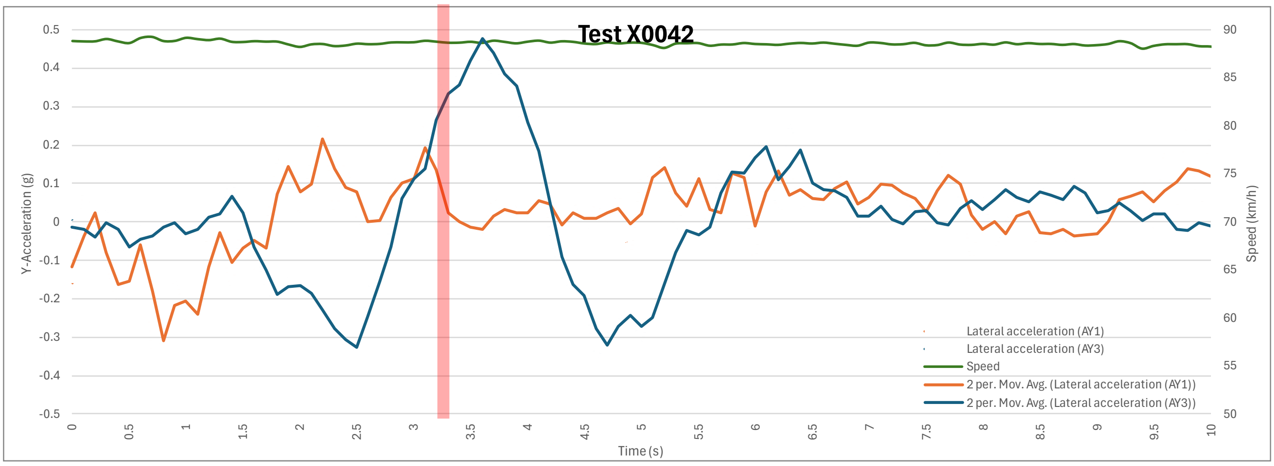
A.3.2 Test X0041 – Low CoG with EBS all OFF

Figure A.14: Test X0041 – roll and yaw rate (EBS all OFF)



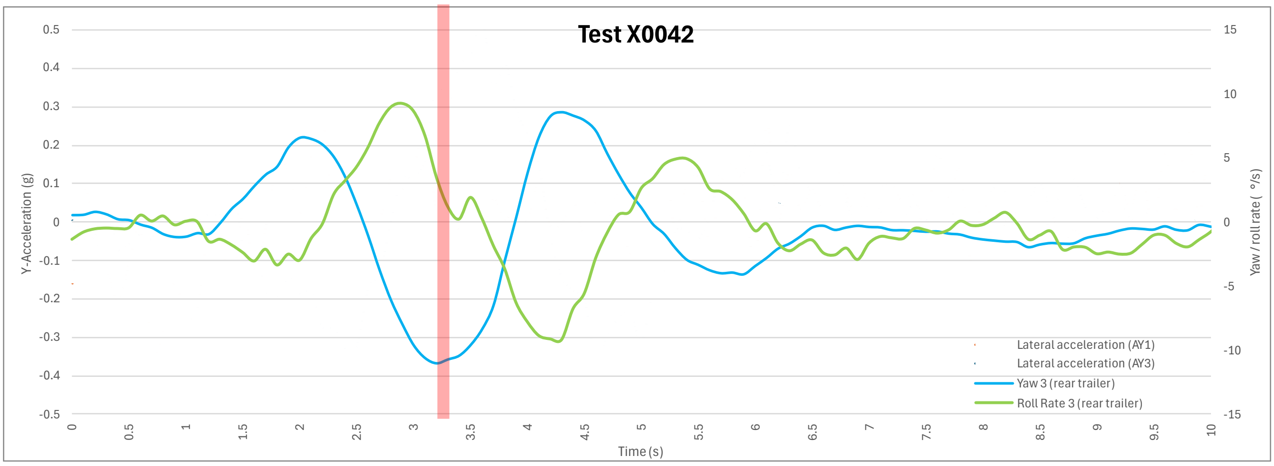
A.3.3 Test X0042 – Low CoG with EBS all OFF

Figure A.15: Test X0042 – lateral acceleration (EBS all OFF)



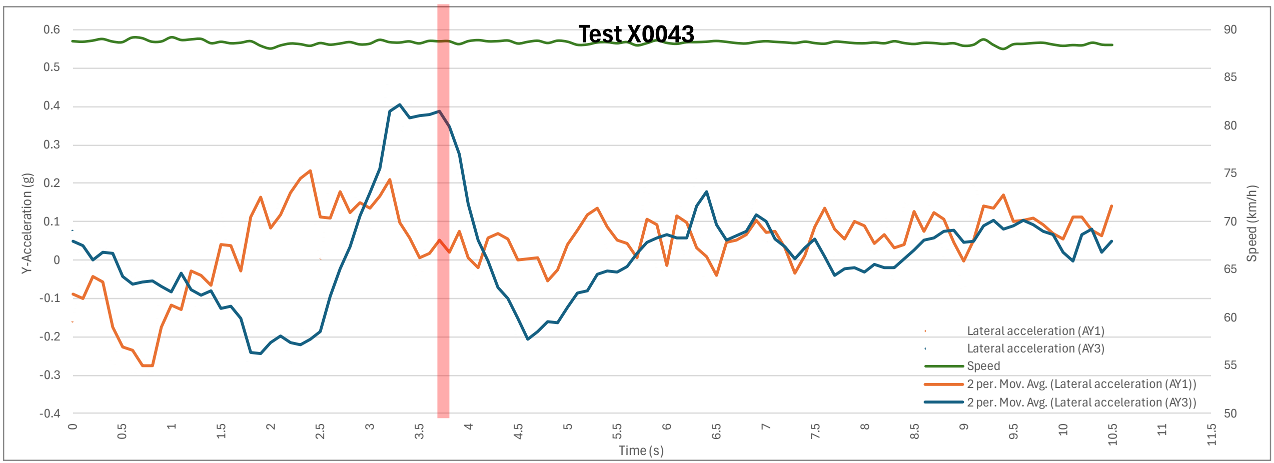
A.3.4 Test X0042 – Low CoG with EBS all OFF

Figure A.16: Test X0042 – roll and yaw rate (EBS all OFF)



A.3.5 Test X0043 – Low CoG with EBS all OFF

Figure A.17: Test X0043 – lateral acceleration (EBS all OFF)



A.3.6 Test X0042 – Low CoG with EBS all OFF

Figure A.18: Test X0042 – roll and yaw rate (EBS all OFF)

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