ARTSA's Brake Test Investigation – Part 1

ARTSA recently commissioned two separate investigations into the brake performance of semi-trailers. The tests were done to provide a basis for the recommendations in the ARTSA brake code. In this article I want to describe the results of an investigation into brake balance on a semi-trailer with various brake set-ups. Later articles will consider the performance of Antilock brakes (ABS) and Electronic Stability Control (ESC).

Stopping tests were conducted using a semi-trailer that had been modified so that the brake level on each axle could be set. Effectively, the brake level could be altered on each of the three axle groups by independently setting the brake air pressure. The maximum deceleration that could be achieved without the combination vehicle leaving a curved test lane was tested.

The tests were conducted by the Australian Road research Board (ARRB) at DECA's Shepparton test track. ARTSA gratefully acknowledges the excellent commitment of ARRB and the financial sponsorship of the Queensland Department of Transport and Main Roads.

The tests were modelled on the 'braking in a curve test' which is in the US braking rule FMVSS 121. This rule requires demonstration of directional control on a 500 ft (152.4 m) radius path of 9 ft (3.7 m) width, by a semi-trailer vehicle that has a prime mover with antilock brakes. The entry speed was 30 mph (48 km/h). In ARTSA's tests there were no electronic brake controls.

The test prime mover and its semi-trailer were modified so that the foundation brakes on each of the three-axle groups were supplied from an independently controllable and regulated air-pressure tanks. Braking was triggered by depressing the clutch pedal, which initiated sudden electrical operation of three solenoid valves, which applied the pre-set air pressure to the brake actuators of each axle group, with the engine disconnected. By varying the levels of the three regulated air supplies, the test vehicles could be set-up to simulate common Australian and European brake setups.

Typical Australian prime mover and trailer setting were made. These did not have load-sensing brakes. The Australian prime-mover ("ADR prime-mover") had 75 per cent brake capacity on the steer axle compared to the European ("ECE prime-mover") prime mover and the Australian prime-mover had 115% drive –axle group brake capacity compared to the European prime-mover. The laden Australian trailer ("ADR trailer") tri-axle group had about 140% brake capability compared to the laden European trailer ("ECE trailer").

For some tests the lightly laden and half-laden Australian trailer group was set-up to simulate load-sensing brakes; that is, the brake levels decrease as the weight on the axle decreases. Load-sensing brakes of the Australian set-ups were simulated by setting the trailer brake air pressure to 65 per cent of the full-load value ("ADR LSV"). The European truck and European trailer brakes were set to comply with the international brake rule ECE Regulation 13, which is mandated in Europe. A certified European brake calculation program was used to determine the necessary settings. The European set-ups both have simulated load-sensing brakes as this has been a long-time requirement in rule ECE R13. The European load-sensing valve set-ups are lower than 65 per cent.

Tests were conducted with four different load levels as shown in the table. A satisfactory brake set-up can achieve relatively high deceleration levels without losing directional control for all the loading conditions.

During testing, the brake control level was increased progressively until the vehicle could not be stopped within the 3.7 m wide lane on a wetted track. When a failure occurred, the brake control level was set to the previous pass level and the previous test was verified. This was the recorded pass level. Both the prime mover and the trailer had disk brakes and air-bag suspensions the rear axle groups. The steer tyres were 295/80R whilst all other tyres were 11R22.5. Preliminary straight-line tests were conducted to determine the force levels that each axle group produced at key air pressures.

Results

The graphs show the deceleration results for the six combinations and for the four load conditions that were tested. The best performance occurred when the trailer had load-sensing brakes (ADR LSV or ECE). The best overall performance was achieved by the Australian ADR prime mover pulling the Australian trailer with load-sensing brakes (ADR LSV). This achieved deceleration levels of about 0.25g in all loading conditions. The brake system was well balanced. The ECE prime mover with the ECE trailer was also a good performer. Its unladen deceleration was 0.22g, which was low because of a tendency for steer wheel lock-up (understeer). This highlights another important factor that is not evident in the graphs. The mode of failure needs to be considered.

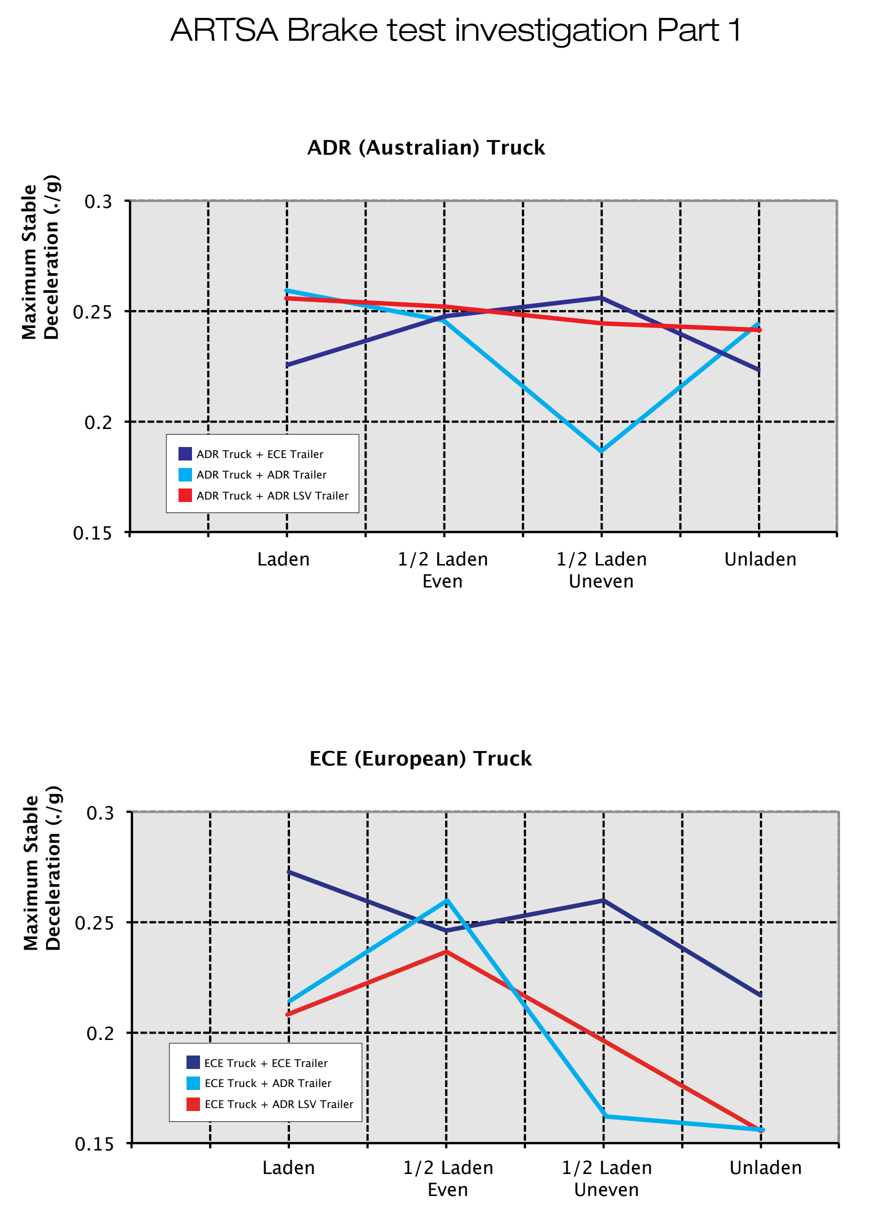
If the performance is limited by front axle lock-up, which typically occurred for the European truck, understeer occurs but the driver can correct this by reducing brake level. If however, the performance is limited by the drive-axle group locking up, which results in jack-knife; it is unlikely that the driver can correct it. Locking up of the trailer tri-axle group leads to trailer swing, which is probably correctable, but it takes longer to control than understeer. Therefore, the way in which the loss of stability occurs is also important. Mixing the European prime mover with the Australian trailer and vice-versa results in poorer performance because these vehicles have poorly balance brakes.

The main conclusion from the tests is that best directional stability occurs when the trailer has load-sensing brakes. For a typical Australian trailer set-up setting the load-sensing valve to give 65% brake level when unladen results in good brake balance. The European combination also gives satisfactory performance because this combination is well balanced. It is brake balance that determines directional stability at high brake levels.

Peter Hart
ARTSA Chair

Calculated axle-group and kingpin weights for each test condition

Axle Group Loads	Unladen (t)	Half Load, Even (t)	Half Load, Drive Heavy (t)	Laden (t)
PRIME MOVER – STEER AXLE	4.90	5.19	5.65	5.7
PRIME MOVER – DRIVE GROUP	5.81	10.92	15.75	16.50
KING PIN IMPOSED LOAD	2.70	8.10	13.27	13.99
TRAILER – TRI-AXLE GROUP	5.90	12.40	7.53	18.81
LOAD WEIGHT AND HEIGHT	0	11.90 AT 1.14M BACK FROM KINGPIN. C OF M HEIGHT OF LOAD IS 2.2M	12.20AT 1.14M BACK FROM KINGPIN. C OF M HEIGHT OF LOAD IS 1.8M	24.22 AT 4.55M BACK FROM KINGPIN. C OF M HEIGHT OF LOAD IS 2.25M
TOTAL VEHICLE WEIGHT	16.61	28.51	28.81	40.82



group weights were: steer axle - 6150 kg, drive group - 8850 kg, tri-axle trailer group - 8650 kg, all up weight - 26,650 kg. Wheel lock-up was observed to occur on the drive- and trailer-axle groups (but not the steer axle) during tests.

There is an optimal tyre footprint for braking. To maintain the optimal tyre footprint the tyre inflation pressure should change with load on the tyre. If properly set, a Central Tyre Inflation (CTI) system can manage tyre pressure according to manufacturer's recommendations. Some stopping tests were conducted with the tyre pressures set to high (656 kPa = 95 psi which is appropriate for a fully loaded tyre) and low (290 kPa = 42 psi which is optimum for the lightly-laden tyre) to determine the effect of tyre pressure on stopping distance.

Results

The tests for each condition were repeated five times and the results for each point shown in the graph are the averages of five tests. The results show:

- With all the tyres at full pressure (656 kPa), the stopping deceleration is about equal whether the ABS is ON or OFF.
- When the tyre pressure is reduced, first on the trailer and then on both the trailer and the truck drive wheels, the average deceleration increases. For the unladen vehicle, it is advantageous to have optimum tyre pressure on the drive- and trailer-axle groups.
- The vehicle with optimum tyre pressure achieves about a 15 % higher average deceleration than the vehicle with high tyre pressure. This occurs because the tyre footprint at low pressure can use the available road friction most effectively.
- The vehicle with the antilock brakes OFF achieves a higher average deceleration than with the antilock brakes ON. The difference is greatest at low tyre pressure. This occurs because the vehicle with low tyre pressure experiences less wheel lock-up that the vehicle with full tyre pressure. Antilock brake operation temporarily releases the brakes on the locked-up group of wheels and then reapplies them. Consequently, during each ABS modulation cycle some stopping distance is 'lost'.
- For reference, the in-service rules (AVSRs) require that a combination vehicle can achieve an average deceleration of 2.8 m/s2 from 35 km/h. This was easily met in all tests.

The tests show that for this test vehicle, setting the tyre pressure low to give about peak road friction, reduced stopping distance by between 10 – 15 per cemt compared to the full-load tyre pressure, because wheel lock-up is not as prevalent. Tyre pressure management (using a CTI) should give improved stopping distance (and wear) performance.

Having antilock brakes active increased stopping distance by ~ 3 per cent (when the tyre pressure is set for peak road friction). A greater difference can be anticipated on a gravel road because modulation will be more frequent. The driver was experienced at brake testing and he probably achieved shorter stops when the ABS was off than a typical driver could.

ABS is known to improve directional stability whilst braking in a turn. This aspect will be discussed in the next article.

Peter Hart
ARTSA Chairman

ARTSA's Brake Test Investigation – Part 3 Roll-Stability Control Effectiveness

This article, which is Part 3 in the series of four articles, describes testing that ARTSA commissioned to investigate the effectiveness of roll-stability control on a semi-trailer. The tests provide a basis for the recommendations in the ARTSA brake code.

Stopping tests were conducted using a semi-trailer that was braked to stop on a sealed, dry, flat and curved roadway having a 'J-turn' radius of 46m (150 ft). The test semi-trailer driver attempted to follow the 'J-turn' within a 3.7 m lane, at a constant speed. The maximum entry speed that could be achieved without the trailer rolling over was determined. Rollover was judged to have occurred when the outrigger safety-wheel touched the roadway. The same driver drove all of the 99 test runs and the driver did not apply the brakes until the performance had been determined.

Testing was conducted with truck Electronic Stability Control (ESC) on or off and with the trailer Electronic Braking System (EBS) on or off. Both the ESC and EBS have a roll-stability control feature. Because the tests did not involve any sudden evasive maneuvers, there was no ABS intervention and no differential ESC intervention. The only response that could be triggered was for the roll-stability control feature to apply the brakes and slow the vehicle for tests with the electronic control system turned on. The prime-mover was a Volvo FH 6x4 and the trailer was MaxiTRANS with a BPW tri-axle set. (See article 2 for additional vehicle details). Volvo and BPW provided the test vehicles without charge and the financial support of the Queensland Department of Transport and Main Roads is also gratefully acknowledged. The tests were conducted professionally by the Australian Road Research Board (ARRB) at DECA's Shepparton test track.

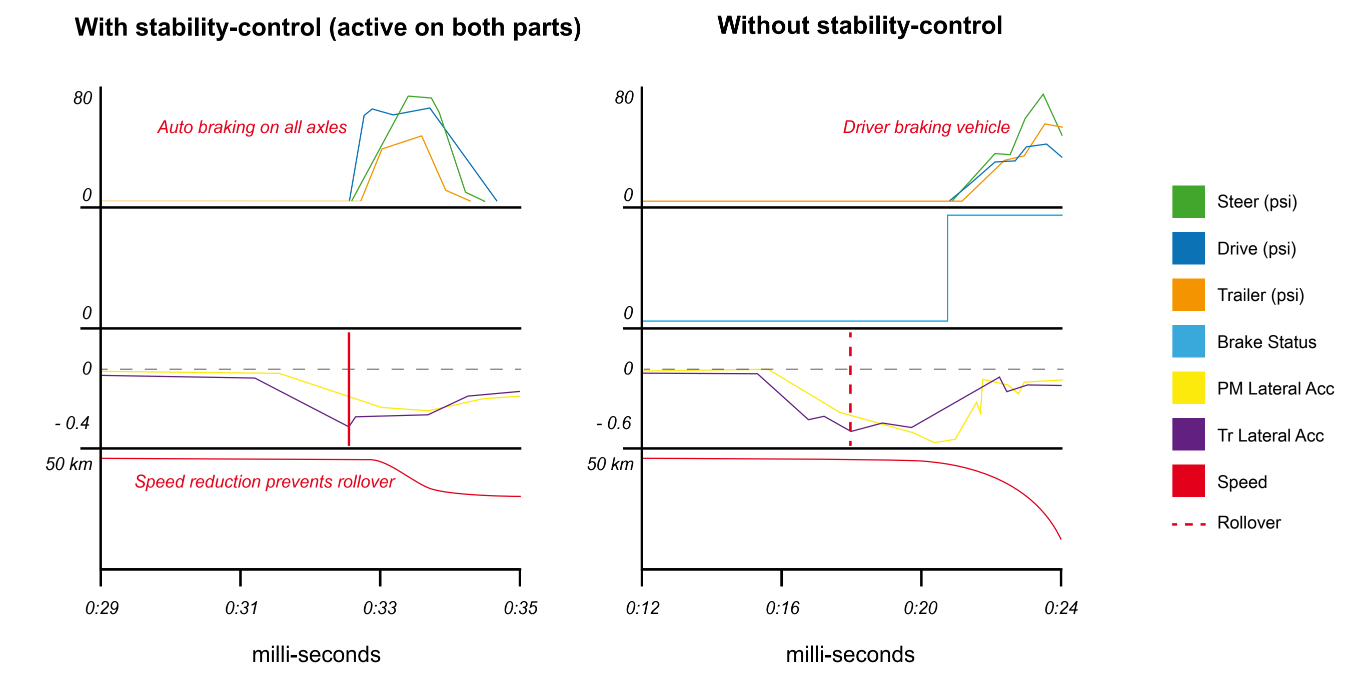
A useful ESC intervention on the prime-mover is shown in Figure 1. Both runs are for the fully-loaded vehicle. Without any stability control active, the trailer tipped over when driven in at 50 km/h. With stability control active on the prime-mover and trailer, the same truck safely travelled the curve at an entry speed of 55 km/h; its speed being automatically slowed to ~ 40 km/h by roll-stability control.

The graph shows the results for all conditions. The likelihood of roll-over is greatest when fully laden as might be expected. In the half-laden condition, the semi-trailer is more likely to roll-over when the load is above the drive-group than above the trailer-group. When the trailer EBS is turned on there is about a 5 km/h (10%) increase in the entry speed that can be tolerated. When the prime-mover ESC is turned on there is about a 10 km/h (20%) increase in the entry speed that can be tolerated without rolling over. Note that the roll-over threshold (SRT) for the fully laden vehicle without stability control intervention can be calculated from the test results: SRT ~ 0.394.

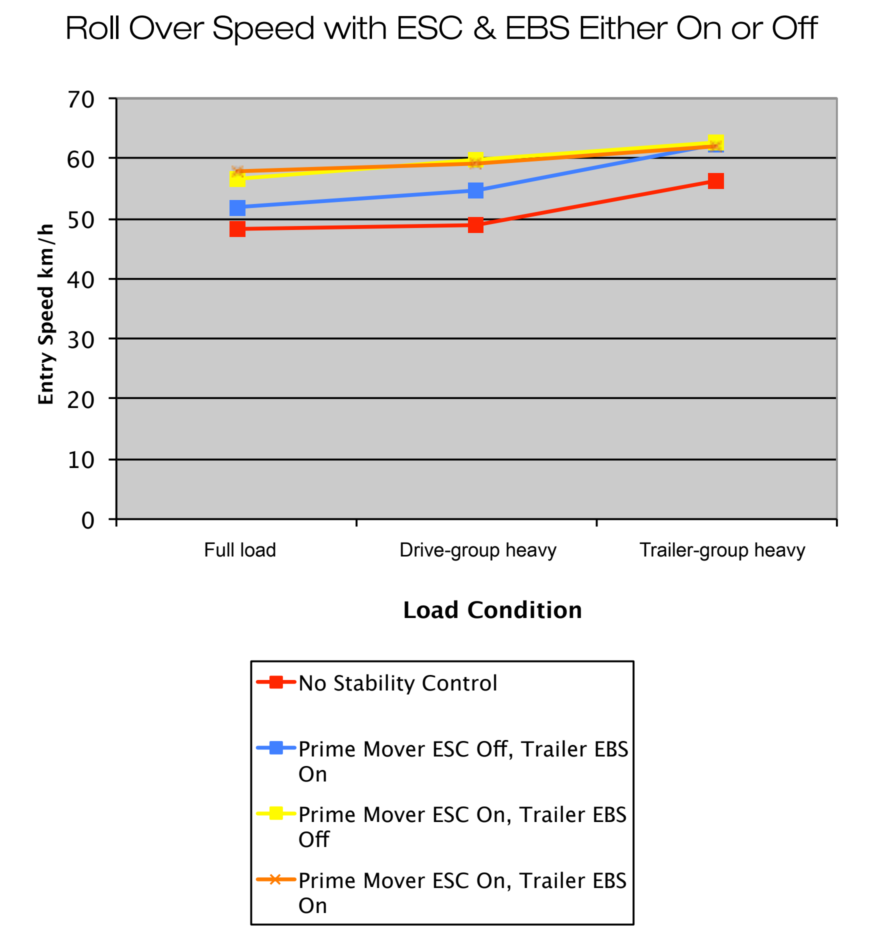
It is not practical to retrofit ESC to a truck whereas it is practical to retrofit EBS to a trailer. So trailer EBS provides an attractive option for operators to protect against roll-over if the prime-mover does not have it. These results are not the full story because ESC and EBS also improve the brake balance when the combination is lightly laden which helps when evasive maneuvers are made. These additional benefits will be considered in Part 4 of this series of articles.

Peter Hart
ARTSA Chairman

Correction: The identifiers on the graph published in the previous Chairman's Technical Article are incorrect and should have been swapped. The deceleration achieved with the Antilock OFF was higher than with the Antilock ON. The description in the text is correct.



Actual test traces for the same load case. (Figure 1)



Results for the three load conditions. Note that for practical reasons 62 km/h was the maximum entry speed. (Figure 2)

Tests Conducted with three different load levels:

FULL LOAD	STEER AXLE WEIGHT	DRIVE-GROUP WEIGHT	TRAILER-GROUP WEIGHT	TOTAL VEHICLE WEIGHT
FULLY LOADED	6.15 T	16.35 T	19.50 T	42.00 T
½ LADEN, DRIVE-GROUP HEAVY	6.25 T	17.35 T	12.05 T	36.65 T
½ LADEN, TRAILER GROUP HEAVY	6.40 T	9.90 T	18.95 T	35.25 T
UNLADEN (UNTESTED)	5.15 T	8.83 T	8.65 T	22.63 T

ARTSA's Brake Test Investigation – Part 4

This is the fourth article about ARTSA'a brake test program. The tests were conducted to measure the performance of new brake technologies on the stopping distance and stability performance of a semi-trailer combination.

The first article considered the brake balance performance of typical Australian and European brake set-ups. The best performance occurred with an Australian prime mover pulling an Australian trailer that had a load sensing valve (LSV) set to 65 per cent when unladen and 100 per cent when fully laden.

The second article reported on the effect of Antilock brakes (ABS) and Central Tyre Inflation (CTI) on the straight-line emergency stopping distance performance of the unladen semi-trailer combination on a dry road. The best performance occurred when the tyre pressure was set to give the optimum footprint, which occurred with tyre pressure at 290 kPa. With optimum tyre pressure, the stopping distance is about 15 per cent shorter than with high tyre pressure (650 kpa). Antilock brakes result in slightly increased stopping distances because brake modulation temporarily releases the brakes, however the change is insignificant with high tyre pressure. The ABS benefit is the improvement in directional control for all tyre pressure levels.

The third article described the cornering stability of the laden semi-trailer combination when the prime-mover and / or the trailer had an active roll-stability system (RSP). For cornering at 60 km/h the prime-mover RSP (which is a feature of the prime-mover Electronic Stability Control system) gives about a 10 km/h safety benefit whilst the trailer RSP gives about a 5 km/h safety benefit.

This article concerns Electronic Stability Control (ESC). For the prime-mover, ESC is an intelligent electronic brake control system that can activate selected prime-mover brakes and / or all the trailer brakes keep the vehicle on, or close to the desired path. To do this, the system monitors the forward velocity, the yaw velocity, the stopping deceleration, the cornering deceleration, and the driver's control inputs. All the sensors and valves communicate electronically. ESC always includes an antilock brake feature, roll-stability program (RSP) and electronic brake management; which takes account of the load on the rear suspension.

The prime-mover was a Volvo FH 540 (6x4) that is equipped with a Knorr Bremse ESC system. The semi-trailer was a MaxiTrans tri-axle trailer with BPW foundation disc brakes and Electronically Controlled Brake System (EBS). During our tests the ESC only activated all the drive--group brakes and all the trailer brakes. Therefore the prime-mover ESC has a two-level intervention. These interventions are intended to slow the vehicle. The autonomous brake action on the drive-group can be different on each side, whereas autonomous trailer braking is always the same on each side.

The trailer EBS includes a roll-stability program (RSP) and because of this it can be regarded as a 'trailer ESC' however, unlike the prime-mover ESC, it cannot activate braking on one side of the trailer only. The trailer EBS will intervene to slow the vehicle when a high risk of roll-over is determined. This action might be triggered during the double lane-change maneouver. The sensors located on the prime-mover will experience the maneouver before the sensors on the trailer do. So intervention by the prime-mover ESC will probably occur before the trailer EBS intervenes.

The performance of ESC was investigated by conducting a double-lane-change maneouver. The vehicle was driven in at successively higher starting speeds and then the same avoidance maneuver was made by the driver. The intended trajectory was a sudden diversion from one lane into the next lane and then back. The same driver achieved about the same steering input each time. The test track was kept wet to promote sliding of the wheels. A run through the course was classified as a 'pass' if the observers and the GPS record declared that the vehicle stayed within the 3.7 m lane width.

The tests were conducted for three loading conditions; which were:

- Unladen. Total weight – 23.6t.
- Half-laden with the added load above the drive-axle group. Total weight = 35.7t.
- Half-laden with the added load above the trailer tri-axle group. Total weight = 35.3 t.

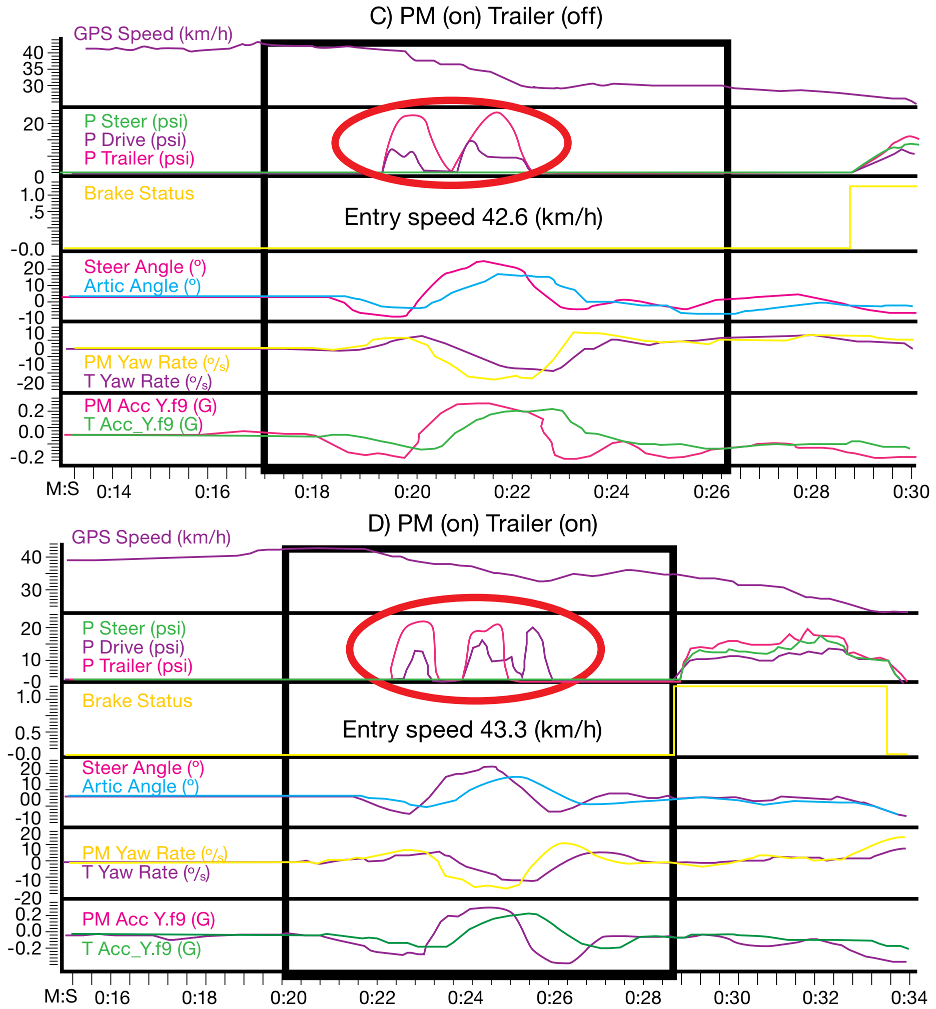
The fully laden case was not tested because it induced a roll-over response, which had been previously tested (see the third article). This round of testing was intended to induce a response to sliding. It was however, noted during preliminary checks that both truck and trailer ESCs did intervene for the fully laden condition.

The results are given in the table. The following important observations were made:

- For this test vehicle, all passes had an exist speed of less than 36 km/h.
- The trailer EBS intervention (which is due to the Roll Stability Program) only occurs when the trailer is loaded.
- The prime-mover ESC intervention occurred for all the load cases.
- The prime-mover steer-axle brakes were never part of the truck ESC intervention.
- The prime-mover ESC initiated two brake pulses whereas the trailer EBS initiated one brake pulse.
- The prime-mover ESC intervention always resulted in the trailer brakes being applied by the prime-mover.
- The intervention brake pressure was always less on the prime-mover than on the trailer.
- The intervention brakes levels are relatively low compared to the levels that might have locked-up wheels. (There would be no point in an ESC intervention causing an ABS response).
- Time trace results showed that the prime-mover ESC intervention occurred before the trailer EBS intervention.
- The prime-mover ESC intervention is more effective and is more likely to occur than the trailer EBS intervention.
- The prime-mover ESC resulted in about a 5 km/h (~ + 12 per cent) improvement in safe entry speed.

The figure illustrates successful interventions by the stability control systems.

Peter Hart
ARTSA Chairman



Results for maximum entry speed resulting in a pass. Brake interventions are indicated by the red ellipse.

LOAD CASE	TRUCK ESC	TRAILER ESC	ENTRY SPEED KM/H	EXIT SPEED KM/H	BRAKE INTERVENTIONS OCCURRED		
					STEER AXLE	DRIVE GROUP	TRAILER AXLE GROUP
UNLADEN TOTAL 23.6 T	ON	ON	43.8	34.5	NO	YES. TWO PULSES OF ~ 35 KPA	NO
	ON	OFF	43.8*	34.5*	NO	YES. TWO PULSES OF ~ 35 KPA	NO
	OFF	ON	38.8	35.7	NO	NO	NO
	OFF	OFF	38.8*	35.7*	NO	NO	NO
DRIVE HEAVY TOTAL 35.7 T	ON	ON	40.3	30.5	NO	YES. TWO PULSES OF ~ 35 KPA	NO
	ON	OFF	34.8	33.5	NO	YES. TWO PULSES OF ~ 35 KPA	NO
	OFF	ON	35.5	33.2	NO	NO	NO
	OFF	OFF	37.0	34.3	NO	NO	NO
TRAILER HEAVY TOTAL 35.3 T	ON	ON	43.3	35.1	NO	YES. TWO PULSES OF ~ 35 KPA	YES. THREE PULSES OF ~ 140 KPA
	ON	OFF	42.6	30.8	NO	YES. TWO PULSES OF ~ 35 KPA	YES. TWO PULSES OF ~ 140 KPA
	OFF	ON	38.4	33.2	NO	NO	YES. ONE PULSE OF ~ 140 KPA
	OFF	OFF	42.3	35.9	NO	NO	NO

* Because there was no trailer EBS intervention, these results are the same as for the row above.