THE COMPARATIVE TESTING OF SINGLE AND DOUBLE RIDE HEIGHT CONTROL VALVE SUSPENSION CONTROL SYSTEMS

Shane Richardson, Andreas Sandvik, Chris Jones, Nikola Josevski, Wei Pei (Tandy) Pok and Tia Orton
Delta-V Experts
Australia
Paper Number 13-0292

ABSTRACT

The pneumatic control system on heavy vehicle air-bag suspension systems, typically designed in the United States of America (and other parts of the world), have one or two ride height control valves and a relatively complex pneumatic supply piping. BASE have developed a control system using two ride height control valves and simplified pneumatic piping. Handling and ride testing were conducted on: a petrol tanker (prime mover and trailer) fully loaded, half loaded and empty; and a concrete agitator fully loaded and empty with both the Original Equipment Manufacturer (OEM) and BASE suspension control systems. The suspension control systems, test method and results are detailed. On-road testing using two concrete agitators operating over the same route was also evaluated using Global Positioning System (GPS), accelerometer and video. The presented results show improvements in ride and handling with the BASE pneumatic air-bag suspension control system.

INTRODUCTION

BASE is a company that has developed and patented a heavy vehicle suspension air-bag control system. This report details and presents the comparative results of dynamic testing of the BASE system compared to the Original Equipment Manufacturer (OEM) suspension air-bag control systems.

A suspension control system needs to address both ride and handling. The ride is the vertical movement whereas handling is the response to manoeuvring. The suspension disconnects the vehicle from the wheels and tyres and attenuates the inputs from the road into the vehicle (ride) and also maintains the tyre contact with the road so that forces (acceleration, deceleration and cornering) can be extracted (handling). The suspension primarily affects the handling by the amount of pitch, roll and bounce and affects how the vehicle accelerates, decelerates, translates laterally and yaws.

Heavy vehicle (truck, trailer and bus) suspension evolved from horse drawn carriage suspension, which were equipped with leaf springs (wood and steel). Figure 1 illustrates a 1932 dump truck with leaf springs on both axles.

Figure 1: 1932 Oshkosh Model F all-wheel-drive dump truck with leaf springs on the front and rear axles.

Other types of suspensions which have been used on automobiles (and trucks) include: rubber block, coil spring, torsion bar, pneumatic (air) and hydropneumatic (hydraulic and air).

During the late 1990's and early 2000's most trucks moved from steel spring suspension to air-bags. The primary reasons were that the air-bag system was lighter, provided superior ride and reduced the damage to the road surface. The key benefits of an air-bag suspension for heavy vehicles is the ability to control ride height, relatively soft spring rate and load sharing. Air-bag suspensions with one ride height control valve have poor roll stiffness and require anti-roll devices to be included. Rolling of the vehicle on the suspension causes the centre-of-gravity to shift sideways relative to the wheels and this tends to destabilise a vehicle in a turn. The amount of roll depends principally on the suspension's roll stiffness and the suspension roll centre height.

The majority of air-bag suspension control systems used in heavy vehicles in Australia (and other countries around the world) is reliant on a single ride height control valve with air-lines connected in series or different length air-lines from the ride height control valve to the suspension air-bags. When one ride height control valve is used, it is typically offset from the vehicle centreline. Anti-roll-bars are also used to increase the roll stiffness.

This method of control is biased to improve ride quality and has limited handling benefits.

Driscol [1] conducted a study into heavy vehicle (truck) crashes over the period 2003, 2005, 2007 and 2009. Driscol identified that over the period 2003, 2005, 2007 and 2009, inappropriate speed for the conditions and fatigue contributed to cause 51%, 54%, 47% and 42% of the crashes respectively.

VicRoads [2] in a study on 'Heavy Vehicle Rollover' have identified that rollover is a serious problem for the heavy vehicle industry. VicRoads identify that: "*…as little as 1km/h extra will make you roll over.*"

The U.S. Department of Transportation has an ongoing major study on the causes of large truck crashes (Toth [3]). A database containing highly detailed data on serious large truck crashes is currently being created. To date, the NHTSA identified that driver error (including driver fatigue) was a factor in the vast majority of crashes. Additionally, the University of New Brunswick's Accident Research Team (Hildebrand [4]), under contract with Transport Canada, conducted over 50 in-depth investigations of heavy truck collisions over a 3-year period. Contributing factors were identified to include speed, driver inattention, visibility issues, road conditions/design/terrain, driver fatigue, load shift (directional stability), mechanical defects and driver inexperience. The majority of collisions were found to have excessive speed as a factor.

According to the Insurance Institute for Highway Safety (IIHS) [5], *"Truck driver fatigue is a known crash risk. Drivers of large trucks are allowed by federal hours-of-service regulations to drive up to 11 hours at a stretch and up to 77 hours over a 7-day period. Surveys indicate that many drivers violate the regulations and work longer than permitted."*

BACKGROUND

The fundamentals of the BASE system are that it dynamically controls the suspension:

1. Two (2) ride height control valves are used, one is fitted to either side of the vehicle;
2. Each ride height control valve is individually supplied;
3. The air-lines used to supply and distribute the pressurised air are Ø12mm (or Ø0.472");
4. All the air-lines are equal length (i.e. from the supply to the ride height control valve and from the ride height control valve to the suspension air-bags);
5. The separate control for either side means that there is variable roll stiffness.

Figure 2 illustrates the OEM twin axle suspension air-bag control system and Figure 3 illustrates the BASE twin axle suspension air-bag control system.

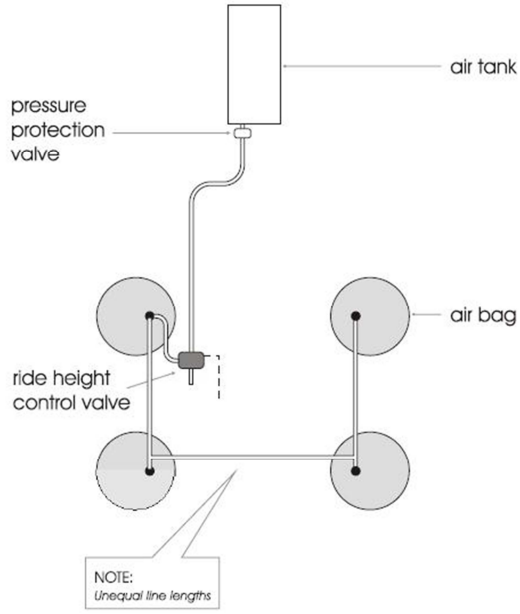

Figure 2: OEM suspension air-bag control system twin axle.

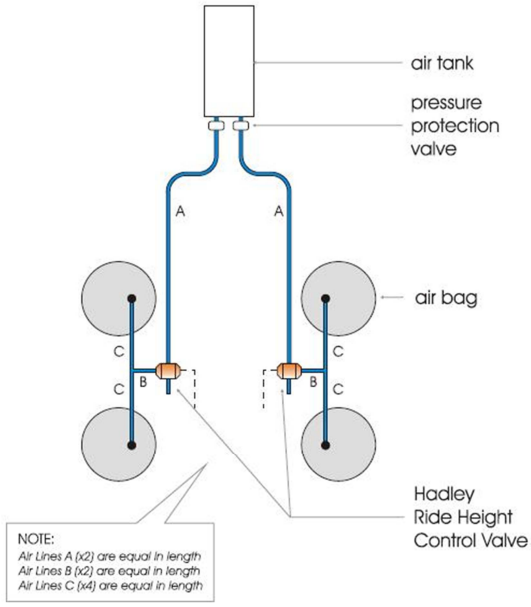

Figure 3: BASE suspension air-bag control system twin axle.

Figure 4 illustrates the OEM 8 air-bag twin axle suspension air-bag control system and Figure 5 illustrates the BASE 8 air-bag twin axle suspension air-bag control system.

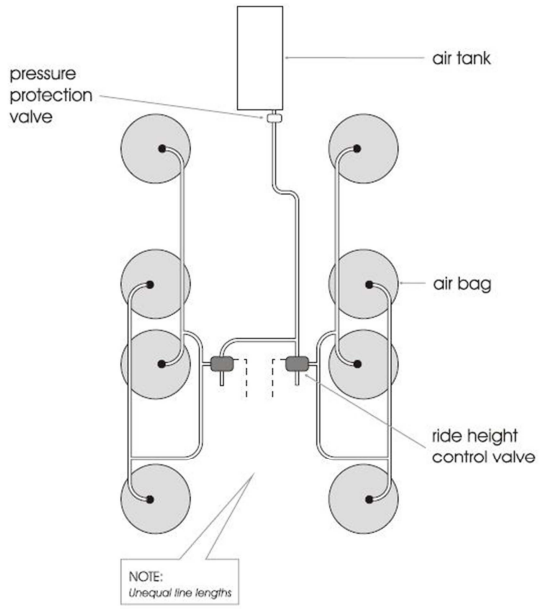

Figure 4: OEM suspension air-bag control system for 8 air-bags and twin axles.

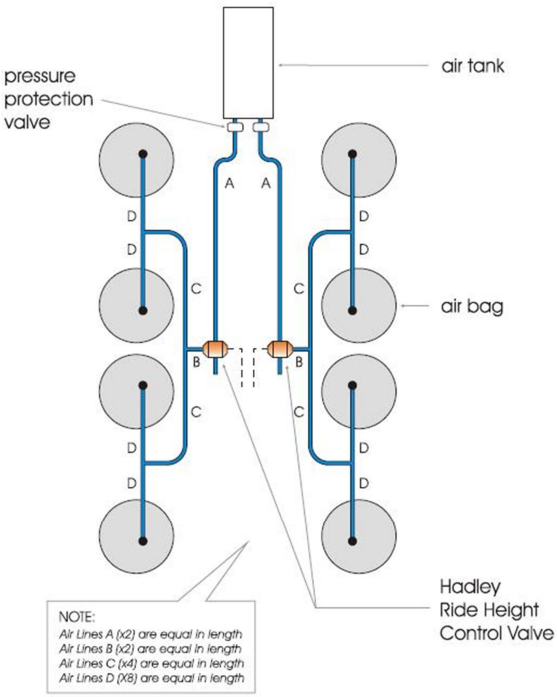

Figure 5: BASE suspension air-bag control system for 8 air-bags and twin axles.

Figure 6 illustrates the OEM 3 axle suspension air-bag control system and Figure 7 illustrates the BASE 3 axle suspension air-bag control system.

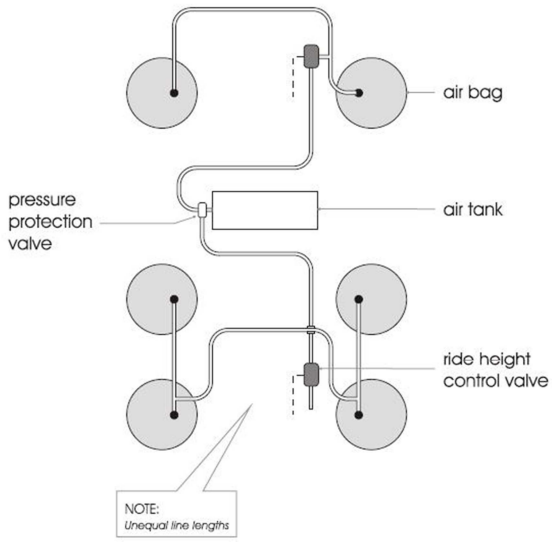

Figure 6: OEM suspension air-bag control system 3 axle.

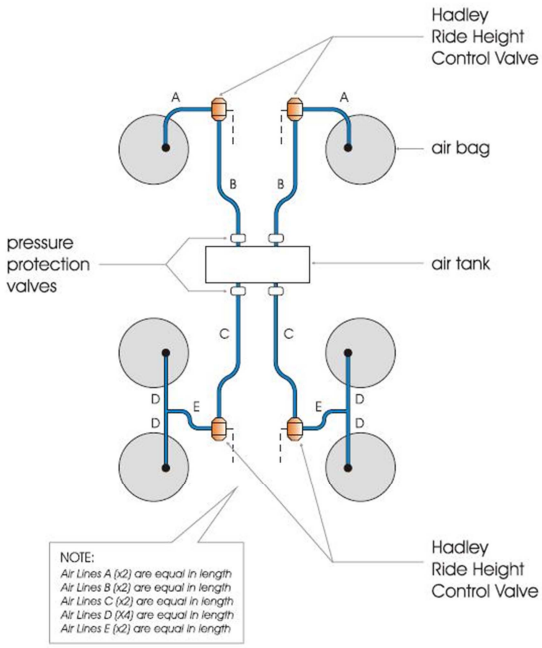

Figure 7: BASE suspension air-bag control system 3 axle.

Figure 8 illustrates the OEM 4 axle suspension air-bag control system and Figure 9 illustrates the BASE 4 axle suspension air-bag control system.

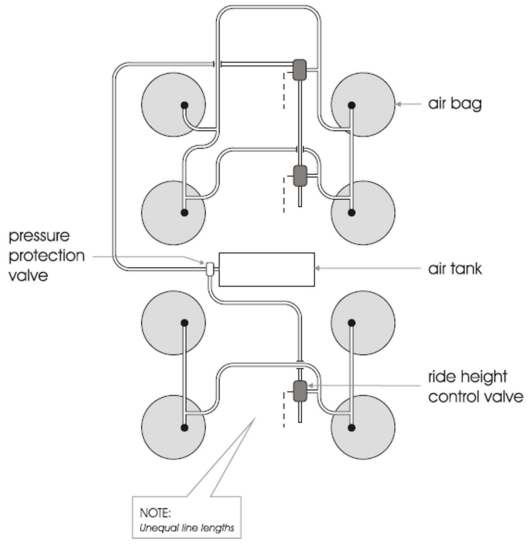

Figure 8: OEM suspension air-bag control system 4 axle.

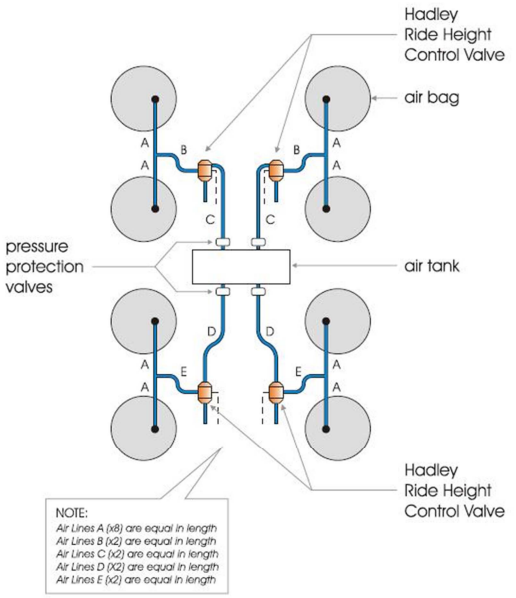

Figure 9: BASE suspension air-bag control system 4 axle.

TESTING

Comparative testing was conducted:

1. At the Australian Automotive Research Centre (AARC) Anglesea, Victoria using the 4.2km long highway circuit. Using both a fuel tanker (prime mover and trailer) and a concrete agitator; and
2. On road using two concrete agitators.

AARC testing

A series of comparative ride and handling tests were conducted on the oval course at Australian Automotive Research Centre (AARC). Two short and two long lane change manoeuvre test sites were positioned on the straight sections of the test course. The exits from both curves at either end were used to evaluate the effect of exiting from a sweeping bend. The vibration tests included the travel to and from the compound to the highway circuit and handling tests on the highway circuit.

Data was collected using:

1. RT3000, a tri-axial accelerometer, velocity, displacement, yaw rate and yaw instrument;
2. Pressure and displacement transducers on the drive axles of the truck and the axles of the trailer;
3. Accelerometers fitted to the drive axles of the truck and the axles of the trailer; and
4. Whole of body vibration was collected using a Svantek SV100.

The dynamic handling tests conducted were:

1. Four (4) modified ISO lane change manoeuvres (2 to the left and 2 to the right); and
2. Exit from sweeping bends at high speed.

The testing methodology used was to activate the instrumentation within the compound of the AARC and record the mass of the truck axle combinations. The trucks were then driven the 4km to the highway circuit over a dirt/gravel road. At the highway circuit the vehicle was then driven in an anti-clockwise direction through the lane change manoeuvres at sequentially increasing speeds. After the data for the lane change manoeuvre was captured, the vehicle was driven around the test course at 80km/h to 110km/h to evaluate the performance of the trucks exiting the sweeping bend. The vehicle was driven back to the compound and either the load and/or the suspension control system was changed. The fuel tanker was tested empty (13,920kg), half loaded (28,970kg) and fully loaded (43,640kg), whereas the concrete agitator was tested empty (17,600kg) and fully loaded (29,260kg).

The lateral acceleration was limited to approximately 60% of the vehicle's estimated limit of lateral acceleration to ensure the safety of the personnel and vehicles used in the testing.

The fuel tanker was provided by Linfox (refer to Figure 10).

Figure 10: The fuel tanker.

The prime mover details were:

1. Manufactured by Freightliner LLC (for DaimlerChrysler Australia/Pacific Pty Ltd);
2. Vehicle Identification Number (VIN) 1FVJF0CV68L999121;
3. Manufactured 10- 2007;
4. Model CL112;
5. GVM 24000 (GCM 50000); and
6. Fitted with RF2013 Airliner suspension.

The trailer details were:

1. Manufactured by Marshall Lethlean;
2. VIN 6D9125RTAM2057066;
3. Manufactured in 1991; and
4. Fitted with a BPW Transpec air-bag suspension.

The concrete agitator was provided by XL Concrete, refer to Figure 11.

Figure 11: The XL Concrete Agitator.

The concrete agitator details were:

1. Manufactured by Kenworth Trucks (for Paccar Australia Pty Ltd);
2. VIN 6F5000000AA443511.

The fuel tanker was driven by a Linfox employee. The concrete agitator was driven by an XL Concrete employee.

Figure 12 illustrates the lateral acceleration data collected during the short course lane change with a fully loaded fuel tanker at speeds of approximately 60km/h.

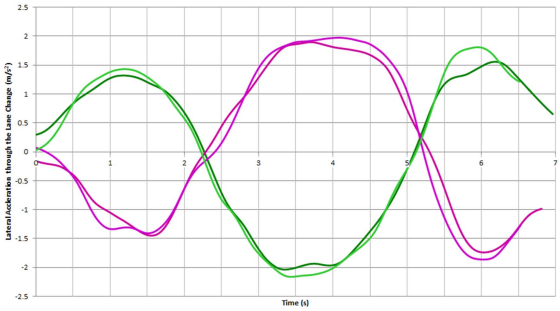

Figure 12: A representative plot of lateral acceleration vs time of four lane change manoeuvres (two turning left/right/left and two turning right/left/right) for the short course lane change with a fully loaded fuel tanker at a speeds of approximately 60km/h. The peak lateral acceleration was extracted from each individual set of test data.

Figure 13 to Figure 24 illustrate the fuel tanker testing for both the short and long lane change manoeuvre courses:

1. The blue lines are the OEM suspension control system on both the prime mover (PM) and trailer (T).
2. The brown lines are the prime mover with the BASE and trailer with the OEM suspension control system
3. The light brown lines are the BASE control system on both the prime mover and trailer.

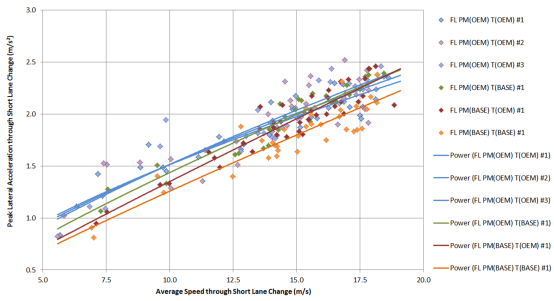

Figure 13: Fully loaded fuel tanker –Peak Lateral Acceleration (Short Lane Change).

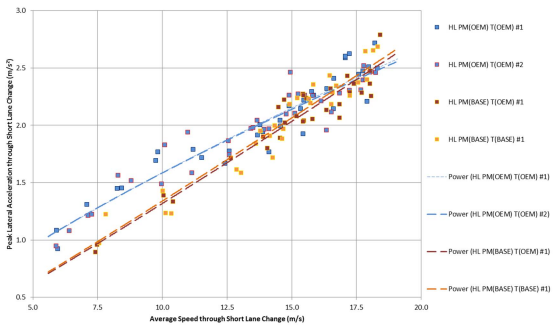

Figure 14: Half loaded fuel tanker –Peak Lateral Acceleration (Short Lane Change).

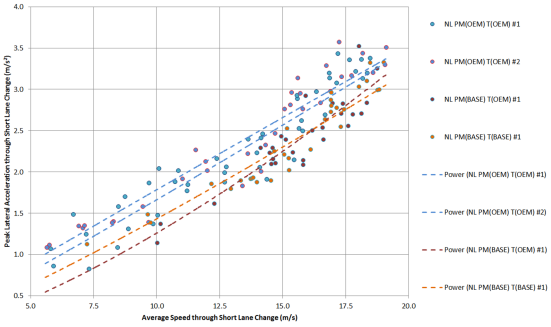

Figure 15: Empty (no load) fuel tanker –Peak Lateral Acceleration (Short Lane Change).

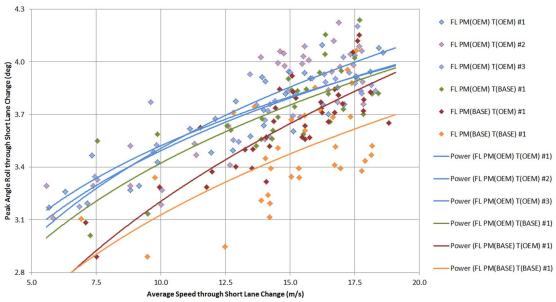

Figure 16: Fully loaded fuel tanker – Peak Roll Angle (Short Lane Change).

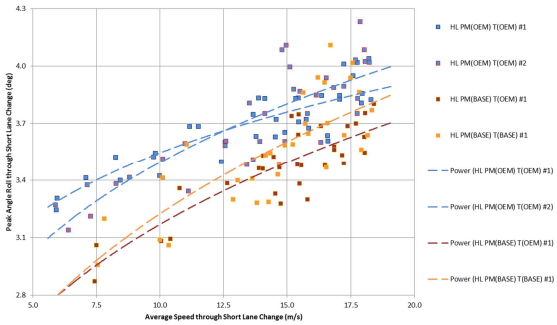

Figure 17: Half loaded fuel tanker – Peak Roll Angle (Short Lane Change).

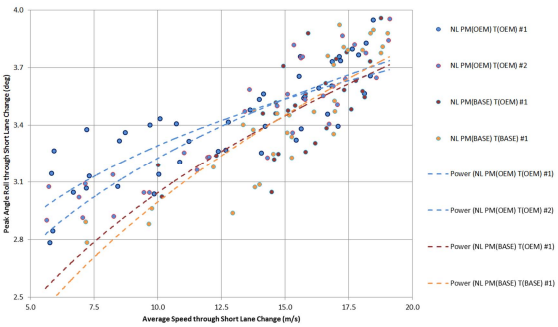

Figure 18: Empty (no load) fuel tanker – Peak Roll Angle (Short Lane Change).

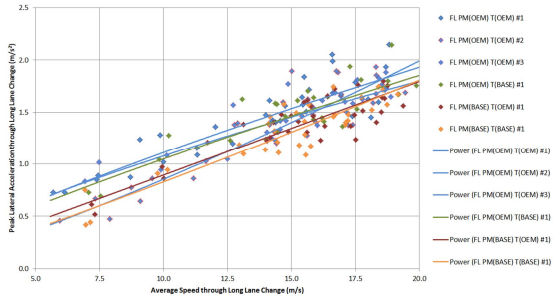

Figure 19: Fully loaded fuel tanker – Peak Lateral Acceleration (Long Lane Change).

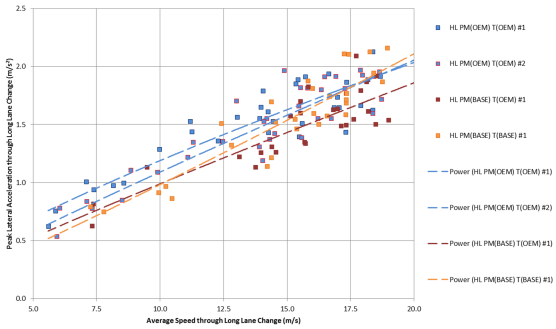

Figure 20: Half loaded fuel tanker – Peak Lateral Acceleration (Long Lane Change).

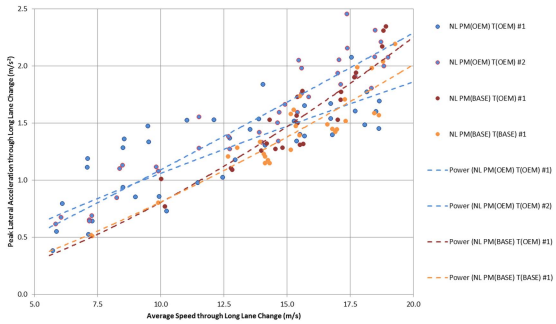

Figure 21: Empty (no load) fuel tanker – Peak Lateral Acceleration (Long Lane Change).

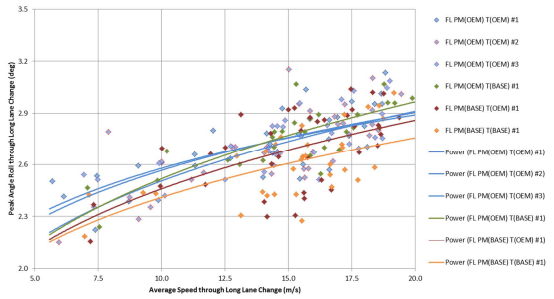

Figure 22: Fully loaded fuel tanker – Peak Roll Angle (Long Lane Change).

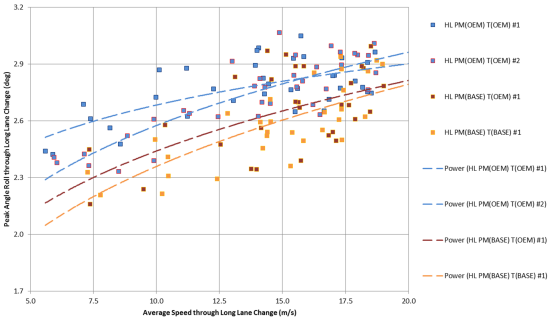

Figure 23: Half loaded fuel tanker – Peak Roll Angle (Long Lane Change).

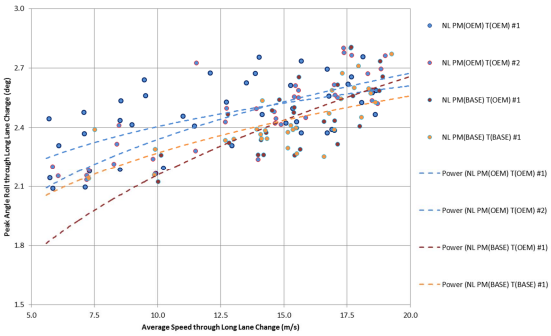

Figure 24: Empty (no load) fuel tanker – Peak Roll Angle (Long Lane Change).

Figure 25 to Figure 32 illustrate the concrete agitator testing for both the short and long lane change manoeuvre courses:

1. The purple lines are the OEM suspension control system.
2. The green lines are the BASE suspension control system.

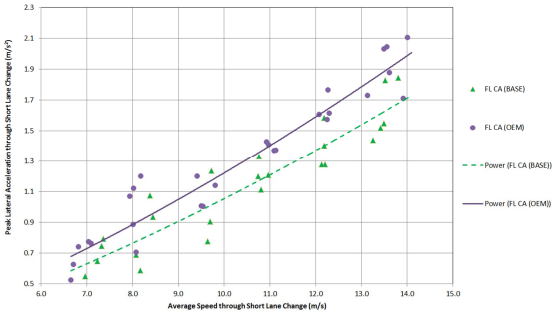

Figure 25: Fully loaded concrete agitator – Peak Lateral Acceleration (Short Lane Change).

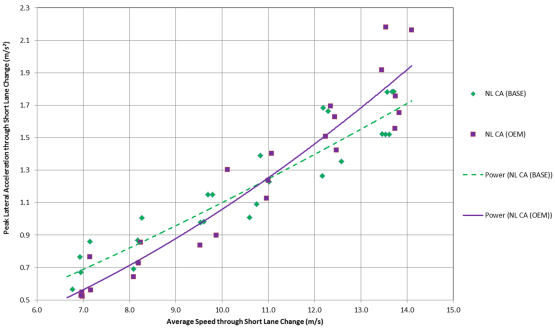

Figure 26: Empty (no load) concrete agitator – Peak Lateral Acceleration (Short Lane Change).

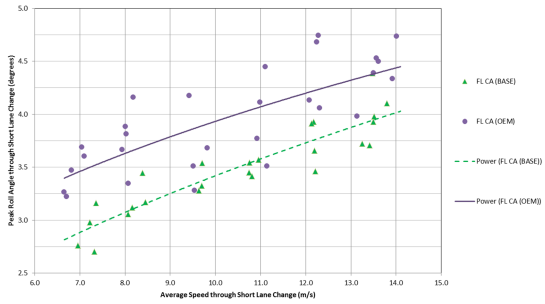

Figure 27: Fully loaded concrete agitator – Peak Roll Angle (Short Lane Change).

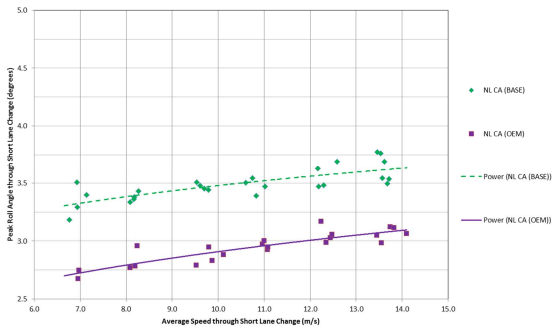

Figure 28: Empty (no load) concrete agitator – Peak Roll Angle (Short Lane Change).

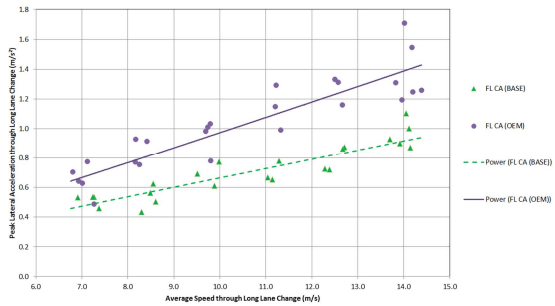

Figure 29: Fully loaded concrete agitator – Peak Lateral Acceleration (Long Lane Change).

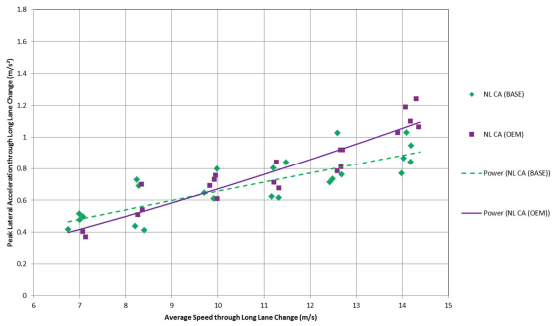

Figure 30: Empty (no load) concrete agitator – Peak Lateral Acceleration (Long Lane Change).

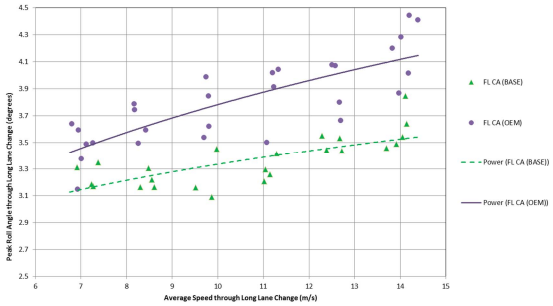

Figure 31: Fully loaded concrete agitator – Peak Roll Angle (Long Lane Change).

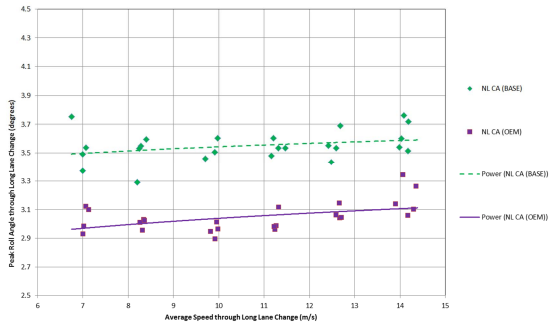

Figure 32: Empty (no load) concrete agitator – Peak Roll Angle (Long Lane Change).

Figure 33 and Figure 34 are extracted from the 70km/h testing of the rear drive axle of the fuel tanker prime mover manoeuvring through the test course. They show a circuit with OEM suspension control (refer to Figure 33) and BASE suspension control (refer to Figure 34) on both the prime mover and tanker.

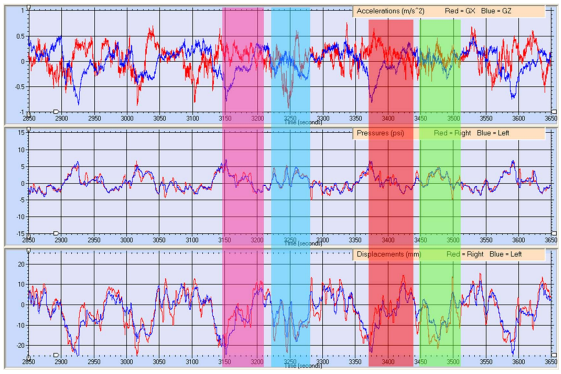

Figure 33: Accelerations, pressures and displacements of the fuel tanker rear drive axle with the OEM single ride height control valve air-bag suspension controller on the prime mover.

Figure 33 is a plot of the accelerations, pressures and displacements of the fuel tanker rear drive axle with the OEM single ride height control valve controlling the suspension air-bags on the prime mover:

1. At 3145s the fuel tanker starts in the first sweeping bend of the circuit and at 3215s the vehicle exits the bend;
2. At 3215s the fuel tanker drives along the first straight section of the test track and manoeuvres through the:
   a. Short course, at 3220s; and
   b. Long course, at 3240s.
3. At 3375s the fuel tanker starts in second sweeping bend of the circuit and at 3430s the vehicle exits the bend;
4. At 3440s the fuel tanker drives along the second straight section of the test track and manoeuvres through the:
   a. Short course, at 3450s; and
   b. Long course, at 3470s.

In Figure 33 the light blue and light green bands identify the short and long lane change manoeuvers and the pink and red bands indicate the sweeping bends.

In Figure 33 both the air pressures run effectively parallel to one another indicating that air-bag pressure on the left side is similar to the right side irrespective of where the vehicle is travelling on the highway circuit; along a straight, through a sweeping bend or manoeuvring through the short or long course land change. Through a complete loop of the circuit the displacement of the drive axles to the chassis varies from +12mm to -25mm (i.e. by 37mm). Figure 33 plot of pressure and displacement is consistent with a single ride height control valve.

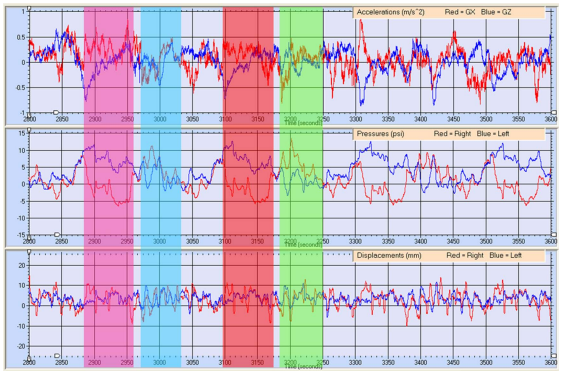

Figure 34: Accelerations, pressures and displacements of the fuel tanker rear drive axle with the BASE single ride height control valve air-bag suspension controller on the prime mover.

Figure 34 is a plot of the accelerations, pressures and displacements of the fuel tanker rear drive axle with the BASE ride height control valves controlling the suspension air-bags on the prime mover.

1. At 2880s the fuel tanker starts in the first sweeping bend of the circuit and at 2950s the vehicle exits the bend;

2. At 2960s the fuel tanker drives along the first straight section of the test track and manoeuvres through the:
   a. Short course, at 2975s; and
   b. Long course, at 3005s.
3. At 3095s the fuel tanker starts in second sweeping bend of the circuit and at 3160s the vehicle exits the bend;
4. At 3170s the fuel tanker drives along the second straight section of the test track and manoeuvres through the:
   a. Short course, at 3180s; and
   b. Long course, at 3220s.

In Figure 34 the light blue and light green bands identify the short and long lane change manoeuvers and the pink and red bands indicate the sweeping bends.

In Figure 34 there is a difference in the left and right air pressures depending on where the vehicle was on the test track. In the straight sections the pressures are parallel to one another, whereas through a sweeping bend or manoeuvring through the short or long course lane change the air pressures are different. Through the sweeping bend the there is a significant difference between the left and right sides, whereas manoeuvring through the short or long course lane change the air pressures change as the vehicle manoeuvres. Through a complete circuit the displacement of the drive axles to the chassis varies from +12mm to -8mm (i.e. by 20mm). Figure 34, a plot of pressure and displacement, is consistent with a two ride height control valves on either side.

The measured Vibration Dose Values for the suspension control systems were:

1. Fuel tanker:
   a. Fully loaded:
      i. OEM 23.5m/s$^{1.75}$;
      ii. BASE 18.7m/s$^{1.75}$.
   b. Half loaded:
      i. OEM 23.3m/s$^{1.75}$;
      ii. BASE 19.5m/s$^{1.75}$.
   c. Empty:
      i. OEM 24.0m/s$^{1.75}$;
      ii. BASE 19.4m/s$^{1.75}$.
2. Concrete agitator:
   a. Fully loaded:
      i. OEM 24.2m/s$^{1.75}$;
      ii. BASE 20.2m/s$^{1.75}$.
   b. Empty:
      i. OEM 20.3m/s$^{1.75}$;
      ii. BASE 21.4m/s$^{1.75}$.

Based on the testing conducted at AARC there is a clear and measureable difference in handling and ride between the OEM and the BASE air-bag suspension control system. The BASE system is quantifiably better optimised for ride and handling.

1. The BASE suspension air-bag control systems reduced manoeuvring peak lateral acceleration by between 4% and 43% for the full, half full and empty fuel tanker; and full and empty concrete agitator.
   a. At lower speeds the handling empty concrete agitator was not improved, but was equivalent to the OEM suspension control system.
   b. In the case of the half full fuel tanker for both the short and long lane change manoeuvre, at the majority of speeds tested the handling was improved. At higher speeds, the handling was equivalent to the OEM suspension control system.
2. The BASE suspension air-bag control systems reduced manoeuvring peak roll angle by between 3% and 19%.
   a. In the case of the empty concrete agitator, for both the long and short lane change manoeuvre at low speeds, the roll angle was not improved. However the rollover collision rates for empty concrete agitators is very low.
   b. In the case of the half full fuel tanker, for the short lane change manoeuvre at the majority of speeds, the roll angle was improved. At the highest speeds the roll angle was equivalent to the OEM suspension control system.
3. In the majority of tests the handling was improved with the BASE system fitted. Overall, the BASE suspension air-bag control systems reduced the average manoeuvring peak lateral acceleration and average peak roll angle by 16% and 10% respectively.
4. A 16% reduction in average manoeuvring peak lateral acceleration would equate to an 8% increase in the rollover tolerance i.e. an OEM truck/trailer would roll at 100km/h whereas a BASE truck/trailer would roll at 108km/h.
5. The pressure measurements of the air-bags show that for the:
   a. OEM single ride height control valve the air pressures on the left and right side of the vehicle are effectively the same.

b. BASE dual ride height control valves the air pressure can be different and is a function of displacement.

6. The displacement measurements of the air-bags show that the magnitude of the displacement for the OEM single ride height control valve is greater than the BASE system (which is consistent with the peak roll results).
7. The ride of the trucks improved with the BASE system fitted. The BASE suspension air-bag control systems reduced VDV by between 17% to 23%.

The test data obtained from exiting the sweeping bends at speeds from 20km/h to 110km/h found no discernible oscillations or control deficiencies with either the OEM or BASE air-bag suspension control systems.

Two independent, highly-experienced truck drivers were used for the testing. The empirical observations of both drivers were that the BASE system significantly improved both ride and handling.

The following link can be used to view a short video of the testing conducted at AARC: http://www.youtube.com/watch?v=MJ_-rKDipmY.

On Road Testing

A series of comparative on-road tests were conducted by pairing two concrete agitators. One of the agitators was fitted with the OEM suspension control system and the second agitator was fitted with the BASE suspension control system.

The concrete agitators were provided by XL Concrete, refer to Figure 35. The OEM suspension control system was equivalent to Figure 4, whereas the BASE suspension control system was equivalent to Figure 5.

Figure 35: The XL Concrete Agitator.

The concrete agitators were manufactured by Kenworth Trucks (for Paccar Australia Pty Ltd), the VINs were;

1. OEM 6F50000005A430174;
2. BASE 6F5000000AA442970.

The concrete agitators were driven by XL Concrete employees, during the course of their normal duties.

Data was collected using BX1500 [5] 'Smarty Black Box' which contains:

1. A tri-axial accelerometer;
2. Global Positioning System (GPS); and
3. High Definition (HD) video.

The BX1500's were fitted to the left side chassis rail with the video camera focussed on the motion of the movement of the suspension air-bag, refer to Figure 36.

Figure 36: A video image of the concrete agitator suspension air-bag (OEM).

The BX1500 software displays the video (upper left) the speed, date and time are displayed at the bottom of the video, the source data files (upper right), the acceleration data (lower left), the heading (lower centre) and Google map (lower right), refer to Figure 37 and Figure 38.

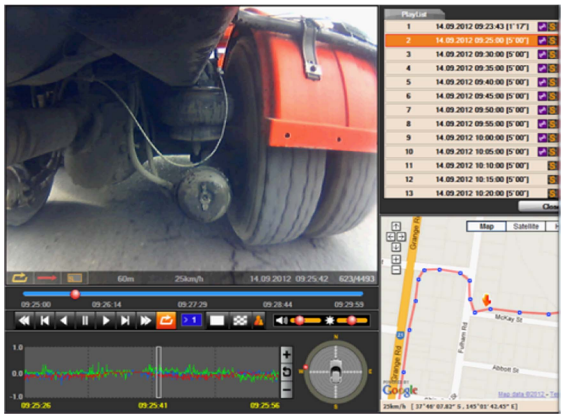

Figure 37: Concrete agitator with OEM air-bag suspension control system.

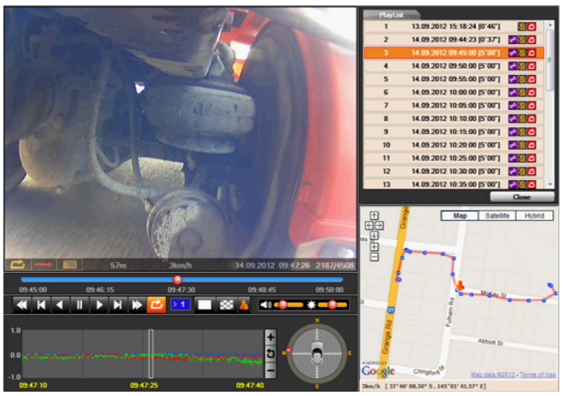

Figure 38: Concrete agitator with BASE air-bag suspension control system.

Comparing the magnitude of the green (vertical vibration) of the OEM and BASE air-bag suspension control systems, refer to Figure 39 and Figure 40, further illustrates that the BASE air-bag suspension control system reduces vertical vibration.

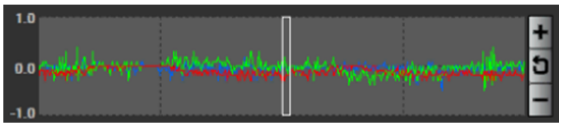

Figure 39: A section of the acceleration plot of the Concrete agitator with OEM air-bag suspension control system. Compare with Figure 40.

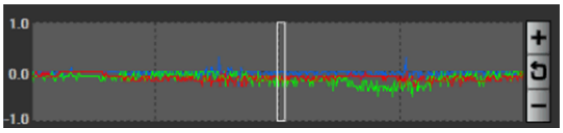

Figure 40: A section of the acceleration plot of the Concrete agitator with BASE air-bag suspension control system. Compare with Figure 39.

The following link can be used to view a short video of the comparative on road testing conducted: http://www.youtube.com/watch?v=P7h91tCDx5k&feature=plcp.

ACKNOWLEDGMENTS

Linfox supported the testing program by providing a prime-mover and trailer, a driver and access to the AARC at Anglesea. Mr Mick Best drove the fuel tanker and is an employee of Linfox.

XL Concrete (Mr Mario Amenta) supported the testing program by providing a concrete agitator and a driver. Mr Joe Montalti drove the concrete agitator at AARC and is an employee of XL Concrete. Subsequently XL Concrete has continued to support with on-road and further concrete agitator specific evaluations.

REFERENCES

[1] Driscol O. P., 2011 Major Accident Investigation Report, National Truck Accident Research Centre, National Transport Insurance. http://www.nti.com.au/files/files/NTARC/2011MajorAccidentInvestigationReport_v10_WS1.pdf

[2] VicRoads is a Victorian State Government Authority in Australia. VicRoads key role is to help provide Victorians with safe and easy connections to the people and places that matter most to them. This includes connecting people to social activities and workplaces as well as connecting goods to domestic and international marketplaces. VicRoads manages over 22,000 kilometres of roads, 3300 bridges, 3.7 million licensed drivers and 4.9 million registered vehicles.

http://www.vicroads.vic.gov.au/Home/Moreinfoandservices/HeavyVehicles/VehicleManagementAndSafety/HeavyVehicleRolloverPreventionProgram.htm

[3] Toth G.R., Radja G. A., Thiriez K. K. and Carra J. S., Large Truck Crash Causation Study in the United States, National Highway Traffic Safety Administration, Paper No. 252. http://www.nhtsa.gov/DOT/NHTSA/NRD/Articles/ESV/PDF/18/Files/18ESV-000252.pdf

[4] Hildebrand & Wilson, Development and Intermediate Findings of a Level III Heavy-Truck Collision Study, Transportation Research Record 1595, Paper No. 971502, p. 39, 1997.

[5] http://www.d-teg.com/products/add_02_ix1000.htm