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Class 8 Heavy-Duty 6x2 Drive Technology

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CLASS 8 HEAVY-DUTY 6X2 DRIVE TECHNOLOGY

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ABSTRACT

Transport Canada (TC), through its ecoTechnologies for vehicles program, commissioned the National Research Council (NRC) to evaluate the load-shifting events of heavy-duty 6x2 drive technology during wheel slip events. The test vehicles included two Class 8 (3-axle) Kenworth T680 long-haul sleeper tractors, two Class 8 (3-axle) Volvo day-cab tractors, and two Freightliner Cascadia sleeper-cab tractors each in 6x2 and 6x4. The use of a flat-deck trailer permitted easily configurable axle loads. The vehicles underwent testing to assess slip induced axle load bias and dynamic axle loading during which wheel load data was collected using wheel force transducers (WFTs). The tests were performed at Transport Canada's Motor Vehicle Test Centre (MVTC) in Blainville, QC on an ice pad made and maintained my PMG Technologies on the DELTA track.

EXECUTIVE SUMMARY

The National Research Council (NRC) was commissioned by Transport Canada (TC), through the ecoTechnologies for vehicles program, to test the viability of 6x2 tractor technology in low traction conditions. The use of 6x2 drive technology allows for reduced fuel consumption through the reduction of drivetrain losses, but some users have expressed concerns over the reduction in traction with one less drive axle. Manufacturers mitigate most of the traction loss through the use of the air suspension by dynamically shifting axle loads to combat any loss of traction, be it real or perceived, compared to a typical 6x4 tractor. The purpose of the test program is to evaluate the magnitude and duration of these load shifting events.

The vehicles tested included a 6x2 and a 6x4 version of each of the following Class 8 (3-axle) tractors: Kenworth T680 long-haul sleeper tractor, Volvo day-cab tractor, and Freightliner Cascadia sleeper-cab. During Phase 2 of testing, the Volvo tractor used in Phase 1 was no longer available, thus a similar model was provided by Volvo as a replacement to continue with testing. During testing, each tractor was equipped with a flat-deck trailer with configurable loads through the use of movable concrete blocks. Axle load bias and dynamic axle loading was measured using wheel force transducers (WFTs) from Michigan Scientific. Testing took place at TC's Motor Vehicle Test Centre (MVTC) in Blainville, QC. The ice pad used for testing, located on a portion of the DELTA track, was built and maintained by PMG Technologies in the winter.

Testing occurred in two phases. The first phase consisted only of the slip induced axle load bias test. Due to availability, only the Kenworth and Volvo tractors were tested in the first phase. Phase 2 resulted in the addition of a second test, the dynamic axle load test, and the Freightliner Cascadia sleeper-cab to the test vehicles. The Freightliner vehicles were part of the original Phase 1 test, but did not arrive in time to participate.

The slip induced axle load bias test consisted of a small, closed loop on the ice pad on the DELTA track. The tractor accelerated from stationary in a straight line until the end of the ice pad was reached, at which point the vehicle made a 180 degree turn for the next start position. One full lap was completed with traction control on and off for each test vehicle.

The dynamic axle load test consisted of one lap around the BRAVO track. The tractor accelerated from stationary on the ice pad, transitioned to the BRAVO track, completed a lap of BRAVO, transitioned back to DELTA, and come to a complete stop.

After observing the results, it was apparent that 6x2 tractors do use their air suspension to shift axle loads for traction assist. All 6x4 tractors maintained as equal axle loading under all conditions. The magnitude and duration of these load-shifting events vary by manufacturer. What is common between all manufacturers is that all 6x2 tractors did not exceed the axle design limit. In other words, load shifting events decrease in magnitude as static axle loads approach their maximum.

According to Volvo, their 6x2 tractor will lift its non-drive axle under light loads to operate as a 4x2 tractor. This is designed to optimize the tractor for operators who spend considerable time with low loads. Bulk hauls, flatbed services, and jobs with declining loads would benefit the most from this feature.

The Kenworth tractor's 6x2 system was proven to be the most variable of the vehicles tested. Under moderate loads, tractor KB's system would only shift axle loads when slip was detected. At any other given time, the tractor maintained normal, static axle loads. The Volvo's system tended towards loading the drive axle with as much load as possible, rarely biasing the non-drive axle. Under low weights, such as an empty trailer, the non-drive axle was lifted entirely,

making the vehicle operate as a 4x2 tractor. The Freightliner's system combines the two methods seen in the other tractors. Freightliner biased its drive axle significantly for traction on acceleration, similarly to Volvo, until it reaches its programmed cutoff speed. At the programmed cutoff speed, the Freightliner system reverts back to equalized axle loads and maintains axle loads as close to equal as possible.

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1 INTRODUCTION

1.1 Purpose

The purpose of the test program was to evaluate the magnitude and duration of 6x2 load shifting events during low-traction induced slippage of the drive wheels and how it compares to the steady-state condition. These load shift events are employed as a traction aid, to temporarily move weight from the dead axle to the driven axle, increasing the vertical load on the driven axle and hence traction. These events generally occur when the vehicle's traction control system detects wheel slip on the driven axle.

1.2 Background

Most major Class 8 tractor manufacturers offer 6x2 for sale in Canada to Canadian fleets and operators, however provincial and territories have varying regulations regarding axle load limits that limit or prohibit their use. There are concerns regarding the reduction in traction (perceived and real) that 6x2 tractors have.

As a strategy to mitigate some of the traction loss, most manufacturers leverage the air suspension system to temporarily transfer axle load from the un-driven axle to the drive axle when wheel slip occurs and then return to normal operation when the wheel slip event has passed.

There are knowledge gaps with respect to these load shifting events, specifically how the cumulative events impact road infrastructure and effects on vehicle dynamics during specific vehicle scenarios. This test program is aimed specifically at addressing knowledge gaps with load shifting events.

This project also is informing Environment and Climate Change Canada's (ECCC) Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations.

1.3 Scope

The scope of this test program was limited to the availability of suitable test vehicles. Specifically, at least one representative of the two different 6x2 drive axle architectures was tested. Each 6x2 drive tractor was matched with a 6x4 drive tractor of the same make and model. Section 2.1 details the test vehicles used.

1.4 Limitations

The traction testing will be performed on a level, natural, low-friction surface. The low-friction surface was an ice surface constructed by PMG Technologies at the Transport Canada Motor Vehicle Test Centre during the winter in Blainville, QC.

Safety requirements dictated that certain vehicle dynamics events could not be realistically studied. These events include adverse yaw, roll stability, and susceptibility to jack-knifing as examples. These events would need to be studied using vehicle dynamics simulation software.

Every effort was made to ensure the test tractors in each set were as identical as possible, however, as the test tractors in vehicle set "V" were graciously supplied by Volvo Trucks North America, the vehicle identified as "VB" was different between Phase 1 and Phase 2 of this test campaign. The vehicle used in Phase 1 was unavailable in their demonstrator fleet for Phase 2 testing.

2 TEST EQUIPMENT

2.1 Test Vehicles

2.1.1 Tractors

All tractors used for this test program were grouped into vehicle sets. Each set consisted of tractors from one manufacturer only. They were the same model and identically equipped in equipment (cab, engine, etc.) with the exception of their drive axles and suspension controllers. Software calibrations of engine, transmission, etc. were not controlled for.

All 6x4 drive tractors were equipped with an interaxle differential lock, as well as axle differential locks for at least one (lead) drive axle. All 6x2 tractors, regardless of axle arrangement, were equipped with a locking axle differential on the drive axle.

Test Vehicle Set K
Vehicle Set K consists of two, Class 8 (3-axle) Kenworth T680 long-haul sleeper tractors. The two tractors were comprised of the following:

- KA: One (1) 6x4 tractor
- KB: One (1) 6x2 tractor, pusher-tag (middle drive) axle arrangement

Test Vehicle Set V
Vehicle Set V consists of two, Class 8 (3-axle) Volvo day-cab tractors. The two tractors are to be comprised of the following:

- VA: One (1) 6x4 tractor
- VB: One (1) 6x2 tractor, tag-tandem (trailing drive) axle arrangement

Test Vehicle Set F
Vehicle Set F consists of two, Class 8 (3-axle) Freightliner Cascadia sleeper-cab tractors. The two tractors are to be comprised of the following:

- FA: One (1) 6x4 tractor
- FB: One (1) 6x2 tractor, pusher-tag (middle drive) axle arrangement

All tractors had their fifth-wheel pivot position set to the mid-point between the rear two axles on the tractor.

2.1.2 Trailer

One trailer for track testing was required. The test trailer for the closed track testing was a standard open flat-deck trailer equipped with a tandem axle set. A drop style flat-deck trailer was an acceptable alternative. The purpose of having an open deck trailer was to facilitate the rapid reconfiguration of ballast to provide variable fifth-wheel (tractor axle) loading during field testing.

2.2 Vehicle Preparation

2.2.1 Test Tires

For this test program, a set of eight standard dual mounted drive tires were required. The tires were mounted on wheel force transducer compatible rims. The tires used in this test program were Michelin XDA drive tires and were 275/80R22.5 in size.

2.2.2 Ballast

The ballast consisted of 26 pre-cast, interlocking concrete blocks, each with a mass of approximately 1000 kg, which gave a total ballast mass of 26000 kg.

Figure 1: Ballast for Track Testing

Figure 1 shows the use of the blocks on the open deck trailer. The ballast was secured in place using chains, load binders, and winch straps after each ballast re-configuration.

For this test campaign, 100% axle load is defined as 10000 kg per axle. This value was selected due to being a very close match to the permissible tandem axle load for Ontario and Quebec highways and had the added convenience of simple mental arithmetic for correlating the lighter loads. Table 1 shows the target axle loads for this test campaign.

Table 1: Tested Tractor Axle Loads (Target)

100%	85%	70%	50%	0%
10000 kg	8500 kg	7000 kg	5000 kg	empty trailer

2.2.3 Instrumentation

A variety of parameters were recorded from the vehicle network in order to add context to the vehicle's behaviour. However, the parameters most pertinent to this test program were the vertical axle loads and the tractive force. Those loads, as well as other forces acting at the tire/ground interface were measured using wheel force transducers (WFT) on the rear wheel stations.

Wheel force transducers were the ideal measurement method as the WFT provides all wheel related parameters (force, moment, speed, and position) and were easily switched between vehicles. A total of four WFT's were employed, one each per rear wheel station. Table 2 shows the instrumentation common to road testing and track testing, as well as the quantity, location, and parameters returned.

Table 2: WFT Details

Instrument	Qty	Capacity	Location	Parameters Measured
Wheel Force Transducer Michigan Scientific LW-2T-100K-S	2	45360 kg (100000 lb)	Drive Axle	Forces: F_x, F_y, F_z Moments: M_x, M_y, M_z Angular: θ, ω Acceleration: a_x, a_z
Wheel Force Transducer Michigan Scientific LW-2T-50K	2	22680 kg (50000 lb)	Dead Axle	Forces: F_x, F_y, F_z Moments: M_x, M_y, M_z Angular: θ, ω Acceleration: a_x, a_z

For the Phase 2 test campaign, the LW-2T-100K-S WFT were replaced with LW-2T-60K-S units as the LW-2T-100K-S units were unavailable. The LW-2T-60K-S WFT were dimensionally and functionally identical to the -100K units, with the exception of a 27 272 kg (60 000 lb) load capacity.

Each WFT requires two modified wheels in order to interface the tire with the WFT. For this program, a special twin wheel rim assembly was required for dual tires and supplied by Michigan Scientific for use with their WFT’s.

Figure 2 shows the typical installation of the WFT on the test tractor. A scaffolding constructed of mechanical strut channel was fabricated to hold the slip-ring restraints and provide a zero reference for the angular position encoders.

Figure 2: WFT Installation

The restraints are required for the WFT amplifiers to accurately transform the rotating coordinate system of the wheel assembly into the stationary fixed coordinate system of the vehicle.

The same tires were used for all trucks tested. The tires used for this test campaign were Michelin XDA 275/80R22.5.

A variety of parameters were available on the vehicle network to be recorded in conjunction with the WFT data. Two different port adapters were required. The Freightliner and Kenworth trucks used the updated (green) "Deutsch" style 9-pin round connector as specified by SAE J1939-13. The Volvo trucks used an automotive style 16-pin D-shaped connector more commonly found on light-duty vehicles colloquially (and inaccurately) referred to as the "OBD-2" port, but is more correctly identified as the datalink connector.

All three truck manufacturers had varying degrees of available data presented through the datalink connector, as well as the uniformity of the data present, which prevents and exhaustive accounting of parameters. However, as a general rule, items such as vehicle speed, transmission gear position, engine related parameters, and some vehicle performance parameters were available across all manufacturers.

One data acquisition (DAQ) unit was required, as well as laptop with DAQ interface software to control the DAQ during each experiment. As all data was broadcast digitally, sample rates and filtering are not applicable. The DAQ was located in the cab of the test truck.

3 TEST PROCEDURES

3.1 Slip Induced Axle Load Bias

3.1.1 Purpose

The purpose of this test was to determine the tractive effort capable of being delivered by the various tractors and the axle loads corresponding to the tractive effort. This test was conducted on a closed track with an ice surface.

3.1.2 Configurations Tested

All test tractors with test trailers (open deck) were used for this test. Vehicles were operated with a variety of ballast distributions.

3.1.3 Facility Required

This test was performed at Transport Canada's Motor Vehicle Test Centre (MVTC) in Blainville, QC, The ice surface was constructed and maintained by PMG Technologies and located on a portion of the DELTA track.

Figure 3: Ice Pad

Figure 3 shows the location of the ice pad at the PMG facility and the traffic flow. The green arrows indicate the starting point for each leg, the red arrows indicate the slow turn.

3.1.4 General Approach

- The tests will be carried out with a variety of tractor axle weights as identified in the ballast configuration section (Section 2.2.2)
- This test will also examine the effects of the tractor's traction control system (TCS) intervention (if so equipped) when enabled vs. disabled.
- The differential lock(s) will be engaged for all test runs.
- The operator was instructed to drive/accelerate as if they were pulling away from an intersection or traffic light. Throttle modulation was at their discretion.

3.1.5 Test Procedure

1. One tractor (6x2 or 6x4) was equipped with wheel force transducers and test tires.
2. The test vehicle was connected to the open-deck test trailer.
3. The ballast was configured to provide the appropriate tractor axle loads for 100% axle load (or as close as possible without exceeding).
4. The tractor-trailer combination vehicle was positioned fully on the ice sheet. The differential lock(s) and TCS is enabled were engaged (on).
5. The DAQ was started.
6. All brakes (parking and service) were released on the tractor and trailer.
7. The driver applied throttle as though pulling away from an intersection, loading dock, traffic light, etc. and modulated the throttle as necessary.
8. As the vehicle approached the end of the ice sheet, the driver slowed down to make the turn. The driver continued to drive until the vehicle was positioned at the opposite starting position.
9. Steps 6 through 9 were repeated for the opposite leg. Two acceleration legs complete one lap of the ice pad. Five laps total were completed for each TCS setting.
10. After five laps were complete, the DAQ was stopped.
11. Steps 4 through 10 were repeated with the TCS disabled (off).
12. The axle load was changed and steps 4 through 11 were repeated.
13. Repeat until all axle loads have been tested. Once all axle loads have been tested, the WFT were transferred to another test tractor and the complete procedure repeated.

3.2 Dynamic Axle Load Test

3.2.1 Purpose

The purpose of this test was to determine the dynamic vs. static loading of the axles as a tractor trailer travels down the road. This test also sought to quantify the magnitude and duration of load shifting events on 6x2 tractors as they operate in the same conditions as their 6x4 counterparts.

3.2.2 Configurations Tested

All test vehicles with test trailer (open deck) were used for this test. Vehicles were operated with a variety of ballast amounts.

3.2.3 Required Test Facility

This test was performed on an ice surface constructed and maintained by PMG Technologies in Blainville, QC. This test was performed on the BRAVO oval track at PMG and utilized the DELTA ice pad for the start/stop position.

Figure 4: PMG Track Layout

Figure 4Figure 5 shows the arrangement of DELTA (yellow) and BRAVO (green) tracks at PMG that were used for this test.

Figure 5: DELTA to BRAVO transition

Figure 5 shows schematically the traffic flow of the start/stop portion of this test on DELTA and the transition to BRAVO.

3.2.4 General Approach

- Tractors equipped with trailers (6x2 and 6x4) were accelerated from a standing start on the DELTA ice pad. As the vehicle gained speed, the vehicle transitioned to clear pavement for the high-speed segment. The various wheel station loads on the tractor were monitored during operation with wheel force transducers.
- The tests were carried out with a variety of tractor axle weights as identified in the ballast configuration section (Section 2.2.2).
- This test also examined the effects of the tractor's traction control system (TCS) intervention (if so equipped) when enabled vs. disabled.
- The differential lock(s) were not engaged for all test runs.
- The operator was instructed to start off as if they were pulling away from an intersection or traffic light. Throttle modulation was at their discretion.

3.2.5 Test Procedure

1. Equip one tractor (6x2 or 6x4) with wheel force transducers and test tires.
2. Connect the tractor to the ballasted trailer. Record the ballast configuration used for each vehicle.
3. The tractor-trailer combination vehicle was positioned fully on the ice sheet (DELTA track)
4. The DAQ was started.
5. All brakes (parking and service) were released on the tractor and trailer.
6. The driver applied throttle as though pulling away from an intersection, loading dock, traffic light, etc. and modulated the throttle as necessary.
7. As the vehicle approached the end of the ice sheet, the driver transitioned to the clear pavement section that led to BRAVO track.
8. The driver completed the transition to BRAVO track and maintained a suitable speed through the curved portion of the track. Once clear of the curve, the driver continued to accelerate until the vehicle achieved an indicated speed of at least 80 km/h on the main straight.
9. The driver slowed down to an appropriate speed for the curve at the end of the “front” straight and maintained that speed through the curved portion of the track.
10. At the end of the curve, the driver transitioned to the DELTA track.
11. Once on the DELTA track, the driver slowed the test vehicle to a complete stop.
12. The DAQ was stopped.
13. The axle load was changed and steps 2 through 12 were repeated until all axle loads were tested. Once all axle loads were tested, the WFT were transferred to another test tractor and the complete procedure was repeated.

4 RESULTS

4.1 Slip Induced Axle Load Bias

Table 3 shows the individual tractor axle loads used for each test. These loads were taken from the WFT z-axis force output. Each axle's left and right stations were summed to provide the net axle force.

Table 3: Tractor Axle Test Loads

			Target Axle Load (static)				
Vehicle	Axle	Function	100% (10000 kg)	85% (8500 kg)	70% (7000 kg)	50% (5000 kg)	
KA	Middle	Driven	9974	8152	7257	5073	Measured Axle Loads (static)
	Rear	Driven	9850	8138	7152	4902	
KB	Middle	Driven	7371	7439	6588	5500	
	Rear	Un-driven	11330	9220	6593	5072	
VA	Middle	Driven	9996	8223	6638	4903	
	Rear	Driven	9935	8179	6573	5034	
VB	Middle	Un-driven	10140	8381	7051	4603	
	Rear	Driven	9951	7954	6915	4909	
FA	Middle	Driven	10052	8241	7195	5116	
	Rear	Driven	9924	8202	7137	4971	
FB	Middle	Driven	10082	8616	7138	6234	
	Rear	Un-driven	9983	8385	6862	3370	

An additional load case of 0%, corresponding to an empty trailer was also tested. As there was no control over the axle load for an empty trailer, the 0% target load was omitted from the load chart show in Table 3.

At the end each ballast change, the combination vehicle was slowly driven in reverse for approximately 10 m and allowed to coast to a stop in neutral. The vehicle was then driven forward slowly for approximately 10 m and allowed to coast to a stop in neutral. This was done to allow the suspension to overcome any internal friction and allow the two axles to settle to their steady-state reading. If adjustments were needed, the ballast was shifted and the settling procedure was repeated.

As a matter of course, the tractor axle load was determined by summing the WFT values for all four corners and averaging them over the two axles. This was only used during the static loading portion

Vehicle KB exhibited a notable trait in that the suspension controller would not permit the middle (drive) axle to be loaded past 7400 kg (approximate) statically. Any attempt to add more weight would result in the balance being transferred automatically to the un-driven axle. As a result, the total load for the tractor (middle + rear axle) was used to gauge the appropriate load to be added. This result is discussed in Section 5.

Table 4: Axle Loads During Slip (100% Load)

				During Slip	
Vehicle	Axle Position	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	9 974	10 327	10 229
	Rear	Driven	9 850	9 972	9 942
KB	Middle	Driven	7 371	8 886	8 847
	Rear	Un-driven	11 330	10 375	10 384
VA	Middle	Driven	9 996	10 126	10 069
	Rear	Driven	9 935	10 088	10 106
VB	Middle	Un-driven	10 140	9 624	9 619
	Rear	Driven	9 951	10 434	10 421
FA	Middle	Driven	10 052	10 176	10 128
	Rear	Driven	9 924	10 029	10 052
FB	Middle	Driven	10 082	10 792	10 604
	Rear	Un-Driven	9 983	9 584	9 717

Table 4 shows the slip induced axle loads versus the static values with the tractor axles at 100% load capacity. In this loading case, regardless of whether the tractor is 6x2 or 6x4, the tractor axle loads remain very close to their static values. The 6x2 tractor axle load controllers for all versions recognizes that the axle loads are at or near the maximum allowable (either design limit or legal limit) and does not initiate any load shifting, keeping the axle loads equalized.

Table 5 shows the slip induced axle loads versus the static values with the tractor axles at 85% load capacity. In this loading case, the 6x4 tractors maintain an equal load distribution across the tractor axles as expected.

Table 5: Axle Loads During Slip (85% Load)

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	8 152	8 445	8 384
	Rear	Driven	8 138	8 237	8 238
KB	Middle	Driven	7 439	9 592	9 322
	Rear	Un-driven	9 220	7 760	7 932
VA	Middle	Driven	8 223	8 301	8 271
	Rear	Driven	8 179	8 286	8 279
VB	Middle	Un-driven	8 381	7 006	7 189
	Rear	Driven	7 954	9 108	8 963
FA	Middle	Driven	8 241	8 354	8 305
	Rear	Driven	8 202	8 211	8 217
FB	Middle	Driven	8 616	9 328	9 741
	Rear	Un-driven	8 385	8 014	7 718

However, the 6x2 tractors now have some room to initiate their load transfer strategies. The 6x2 tractor axle load controllers for all implementations only transfers enough axle load from the non-drive axle to the drive axle to bring the drive axle close to the maximum permissible load which is very close to the 100% load case.

Table 6 shows the slip induced axle loads versus the static values with the tractor axles at 70% load capacity. As with the 100% and 85% loading cases, the 6x4 tractors maintain an equal load distribution across the tractor axles as expected.

Table 6: Axle Loads During Slip (70% Load)

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	7 257	7 504	7 400
	Rear	Driven	7 152	7 231	7 192
KB	Middle	Driven	6 588	8 880	8 795
	Rear	Un-driven	6 593	5 775	5 805
VA	Middle	Driven	6 638	6 821	6 782
	Rear	Driven	6 573	6 750	6 747
VB	Middle	Un-driven	7 051	4 528	4 641
	Rear	Driven	6 915	9 118	9 037
FA	Middle	Driven	7 195	7 327	7 288
	Rear	Driven	7 137	7 167	7 185
FB	Middle	Driven	7 138	8 914	8 906
	Rear	Un-driven	6 862	5 651	5 661

However, the 6x2 tractors now have more room to initiate their load transfer strategies, but they still limit the amount of load placed on the drive axle. In the case of VB, the suspension controller loads the drive axle to close to the maximum permissible load which is very close to the 100% load case. In the case of KB and FB, the suspension controller limits the drive axle load to a value closer to the 85% load case.

Table 7 shows the slip induced axle loads versus the static values with the tractor axles at 50% load capacity. As with the 100%, 85%, and 70% loading cases, the 6x4 tractors maintain an equal load distribution across the tractor axles as expected.

Table 7: Axle Loads During Slip (50% Load)

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	5 073	5 158	5 140
	Rear	Driven	4 902	4 928	4 920
KB	Middle	Driven	5 500	7 105	7 698
	Rear	Un-driven	5 072	4 000	3 467
VA	Middle	Driven	4 903	5 156	5 092
	Rear	Driven	5 034	5 073	5 080
VB	Middle	Un-driven	4 603	959	695
	Rear	Driven	4 909	7 971	8 163
FA	Middle	Driven	5 116	5 268	5 181
	Rear	Driven	4 971	5 093	5 096
FB	Middle	Driven	6 234	8 339	8 359
	Rear	Un-driven	3 370	1 835	1 799

However, the 6x2 tractors now have considerable freedom to initiate their load transfer strategies, but they still limit the amount of load placed on the drive axle. In the case of VB, the suspension controller loads the drive axle to close to the maximum permissible load which is very close to the 100% load case. In the case of KB and FB, the suspension controller limits the drive axle load to a value closer to the 70% load case.

Table 8 shows the slip induced axle loads versus the static values with the tractor axles with an empty trailer. As with the other loading cases, the 6x4 tractors maintain a functionally equal load distribution across the tractor axles as expected.

Table 8: Axle Loads During Slip (Empty)

				During Slip	
Vehicle	Axle	Function	Static Load	TCS on	TCS off
KA	Middle	Driven	n/a[1]	2 850	2 834
	Rear	Driven	n/a[1]	2 616	2 611
KB	Middle	Driven	n/a[1]	5 198	5 277
	Rear	Un-driven	n/a[1]	516	451
VA	Middle	Driven	n/a[1]	2 543	2 531
	Rear	Driven	n/a[1]	2 352	2 354
VB	Middle	Un-driven	n/a[1]	n/a[2]	4 283
	Rear	Driven	n/a[1]	n/a[2]	4 349
FA	Middle	Driven	n/a[1]	2 752	2 703
	Rear	Driven	n/a[1]	2 608	2 636
FB	Middle	Driven	n/a[1]	3 977	3 954
	Rear	Un-driven	n/a[1]	1 335	1 385

1. Static loads were not recorded for empty as there was no control over the load
2. VB middle axle was lifted during empty trailer testing

The static loads were not reported as there was no control over the static values for an empty trailer. The 6x2 tractors now display considerable differences in the amount of load transferred between axles. Manufacturer calibration of the control strategies is very evident with an empty trailer.

In the case of tractor VB, the suspension controller completely lifts the non-drive axle, functionally making it a 4x2 tractor. Virtually all of the trailer's weight is transferred to the drive axle.

In the case of tractor KB, although the non-drive axle is not liftable, the low load value indicates that there is little more than just the axle's dead weight present. Tractor FB has a similar result to tractor KB, but with higher values.

4.2 Dynamic Axle Load Test

The dynamic axle load test results covers the time history of the drive and non-drive axle loads on the tractor as it travels down the road.

4.2.1 Tractor KA, 100% Load

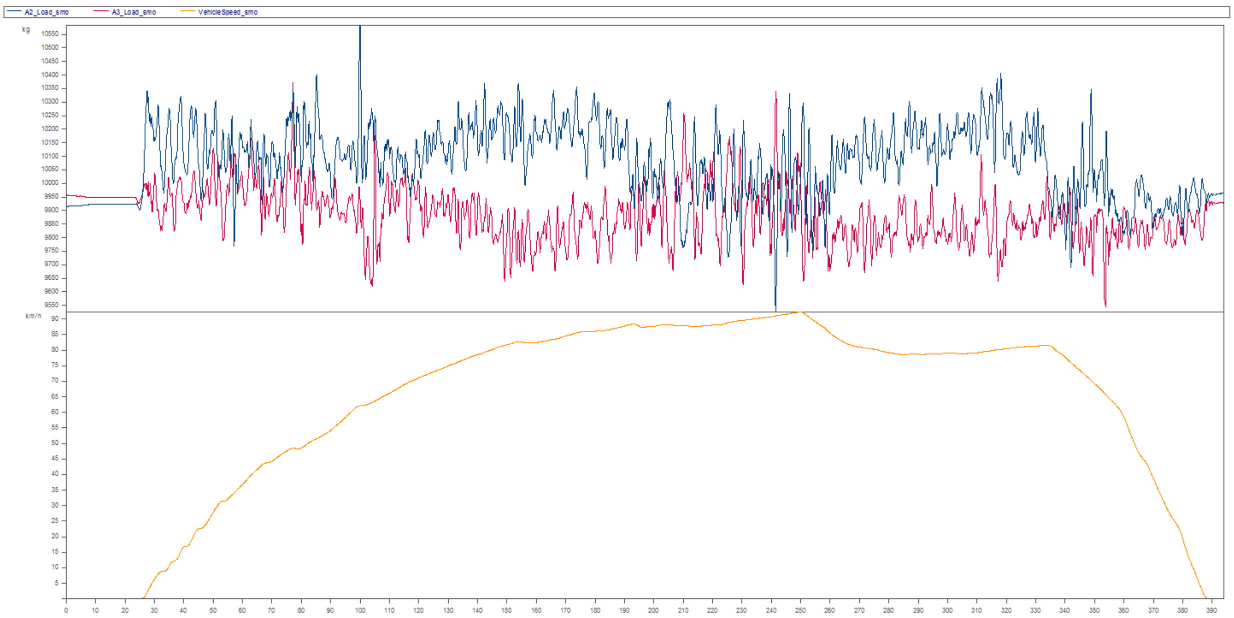

Figure 6: Tractor KA @100% Axle Load

Table 9: Static Axle Load, KA 100%

Axle 2	Axle 3
9974 kg	9850 kg

Figure 6 shows the time history of the axle load on tractor KA for the entire lap. The static load case was 100%. Table 9 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.
Tractor KA, 85% Load

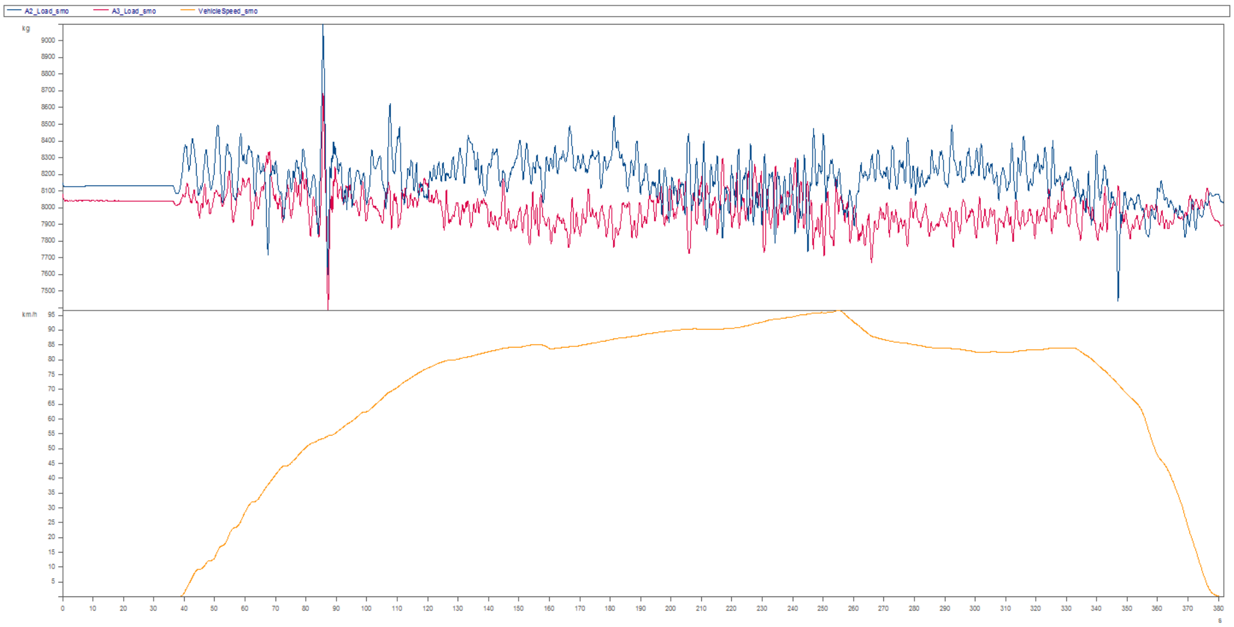

Figure 7: Tractor KA @85% Axle Load

Table 10: Static Axle Load, KA 85%

Axle 2	Axle 3
8152 kg	8138 kg

Figure 7 shows the time history of the axle load on tractor KA for the entire lap. The static load case was 85%. Table 10 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.2 Tractor KA, 70% Load

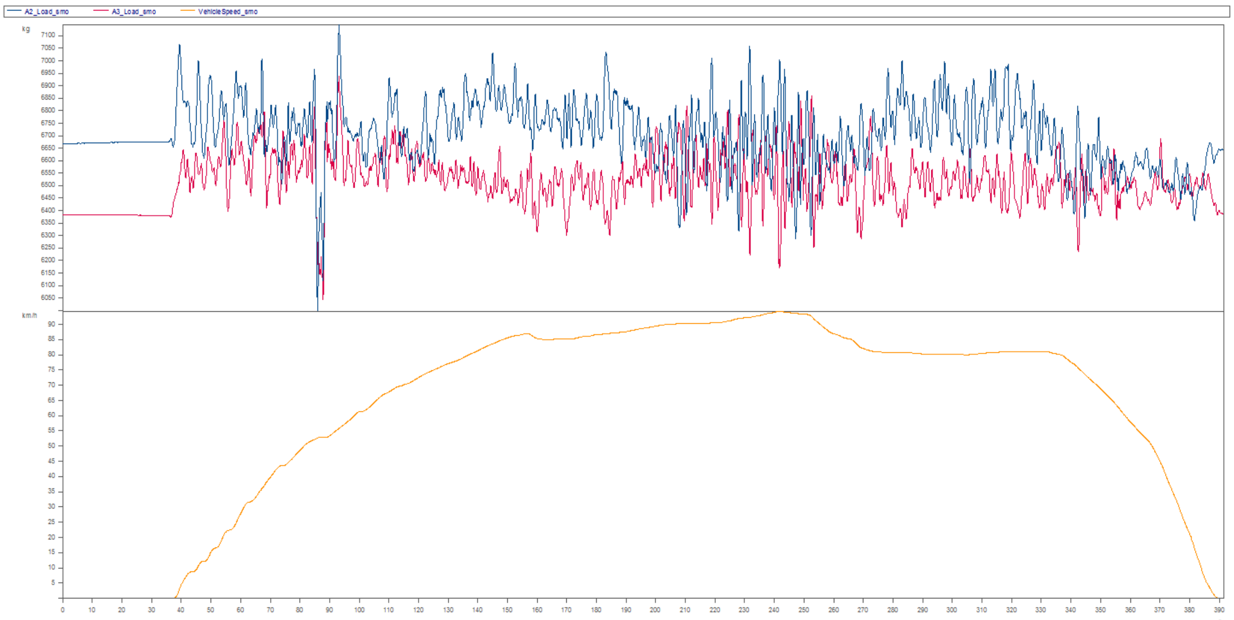

Figure 8: Tractor KA @70% Axle Load

Table 11: Static Axle Load, KA 70%

Axle 2	Axle 3
7257 kg	7152 kg

Figure 8 shows the time history of the axle load on tractor KA for the entire lap. The static load case was 70%. Table 11 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.3 Tractor KA, 50% Load

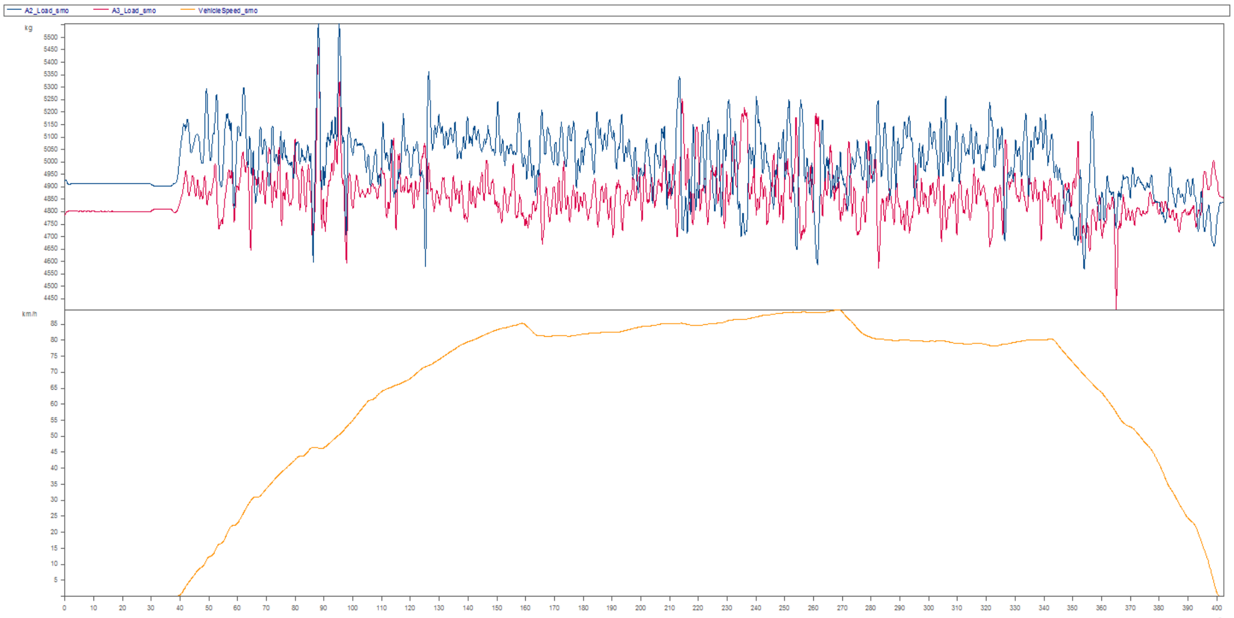

Figure 9: Tractor KA @50% Axle Load

Table 12: Static Axle Load, KA 50%

Axle 2	Axle 3
5073 kg	4902 kg

Figure 9 shows the time history of the axle load on tractor KA for the entire lap. The static load case was 50%. Table 12 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.4 Tractor KA, Empty

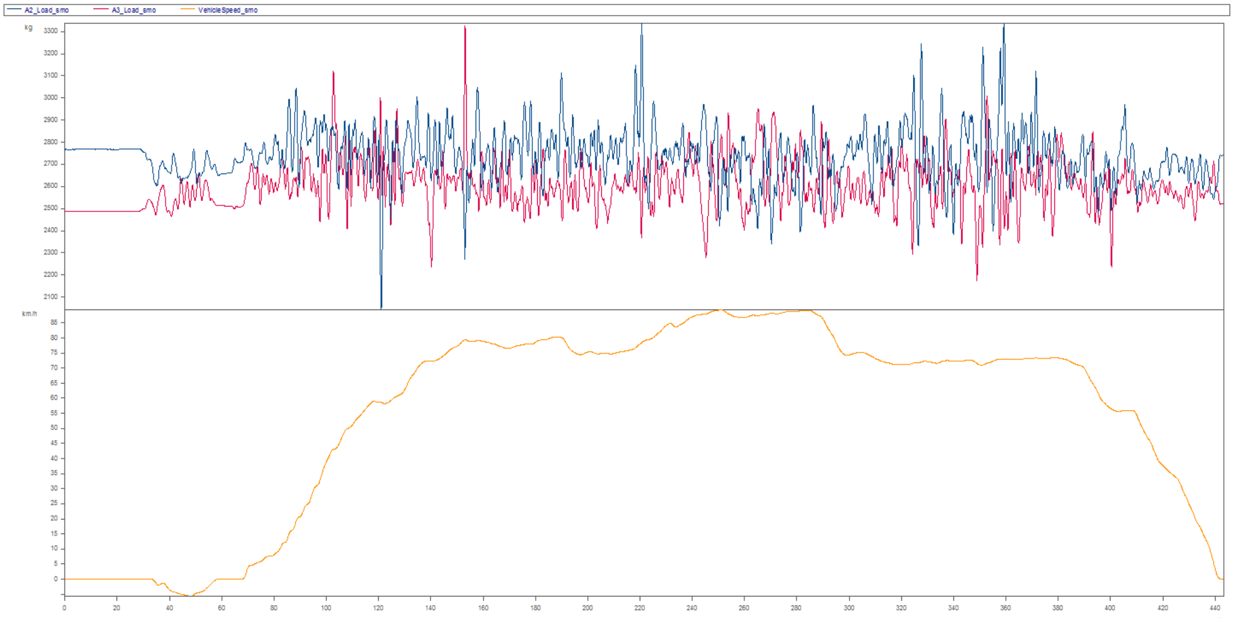

Figure 10: Tractor KA @0% Axle Load

Table 13: Static Axle Load, KA 0%

Axle 2	Axle 3
2767 kg	2488 kg

Figure 10 shows the time history of the axle load on tractor KA for the entire lap. The static load case was 0%. Table 13 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.5 Tractor KB, 100% Load

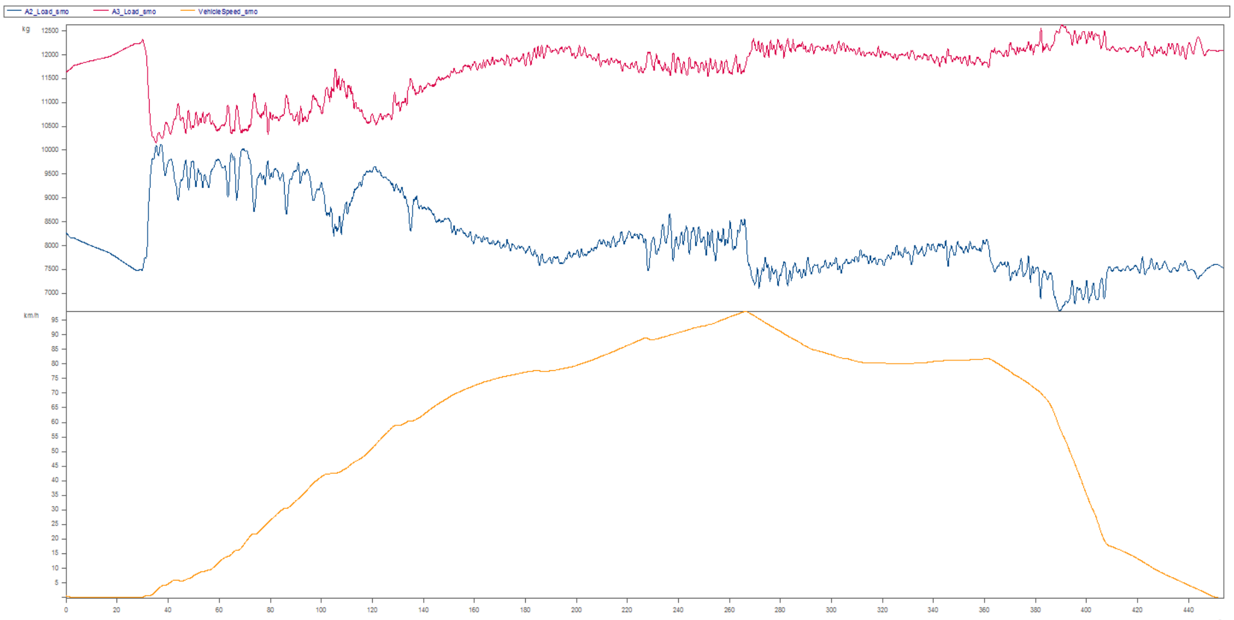

Figure 11: Tractor KB @100% Axle Load

Table 14: Static Axle Load, KB 100%

Axle 2	Axle 3
7371 kg	11330 kg

Figure 11 shows the time history of the axle load on tractor KB for the entire lap. The static load case was 100%. Table 14 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). Tractor KB was notable as the suspension controller capped the maximum drive axle load at approximately 7400 kg static. There was no operator controlled facility to force the system to equalize manually.

As the vehicle started on ice, the tractor's suspension controller immediately biased axle load to the drive axle due to wheel slip. Once the vehicle's control system detected slip, the suspension controller reacts by rapidly evacuating the non-drive axle's air springs, which shifts the non-drive axle's load to the drive axle. The elapsed time for this event is approximately five seconds.

As the vehicle gains speed and wheel slip is eliminated, the suspension controller slowly begins to re-distribute the axle load back to the starting axle loads. The bulk of the re-distribution is performed in approximately 120 seconds from the traction assist load transfer.

4.2.6 Tractor KB, 85% Load

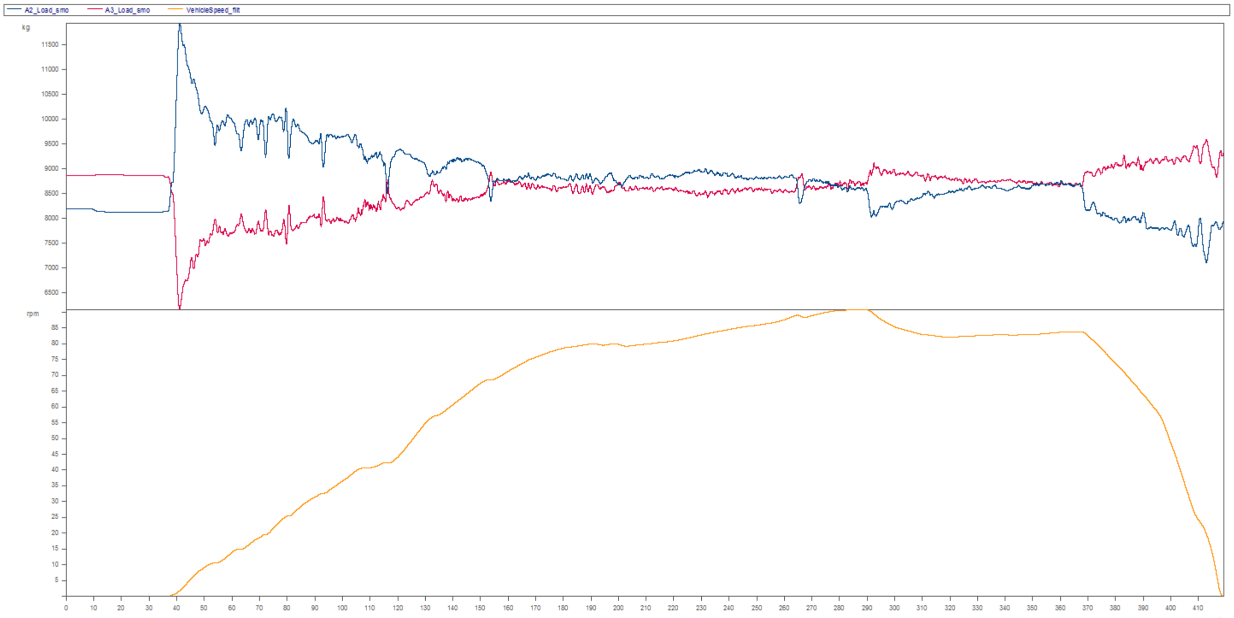

Figure 12: Tractor KB @85% Axle Load

Table 15: Static Axle Load, KB 85%

Axle 2	Axle 3
7439 kg	9220 kg

Figure 12 shows the time history of the axle load on tractor KB for the entire lap. The static load case was 85%.The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). As the vehicle started on ice, the tractor's suspension controller immediately biased axle load to the drive axle due to wheel slip.

The programming of the suspension controller for vehicle KB is such that the drive axle is only slightly biased with additional load for traction assist. There is no provision to force the system to equalize manually. Once the vehicle's control systems detect slip, the suspension controller reacts by rapidly evacuating the non-drive axle's air springs, which shifts the non-drive axle's load to the drive axle. The elapsed time for this event is approximately five seconds.

As the vehicle gains speed and wheel slip is eliminated, the suspension controller slowly begins to equalize the axle loads. The bulk of the equalization is performed in approximately 12 seconds with the remainder slowly occurring over a period of about 100 seconds.

4.2.7 Tractor KB 70% Load

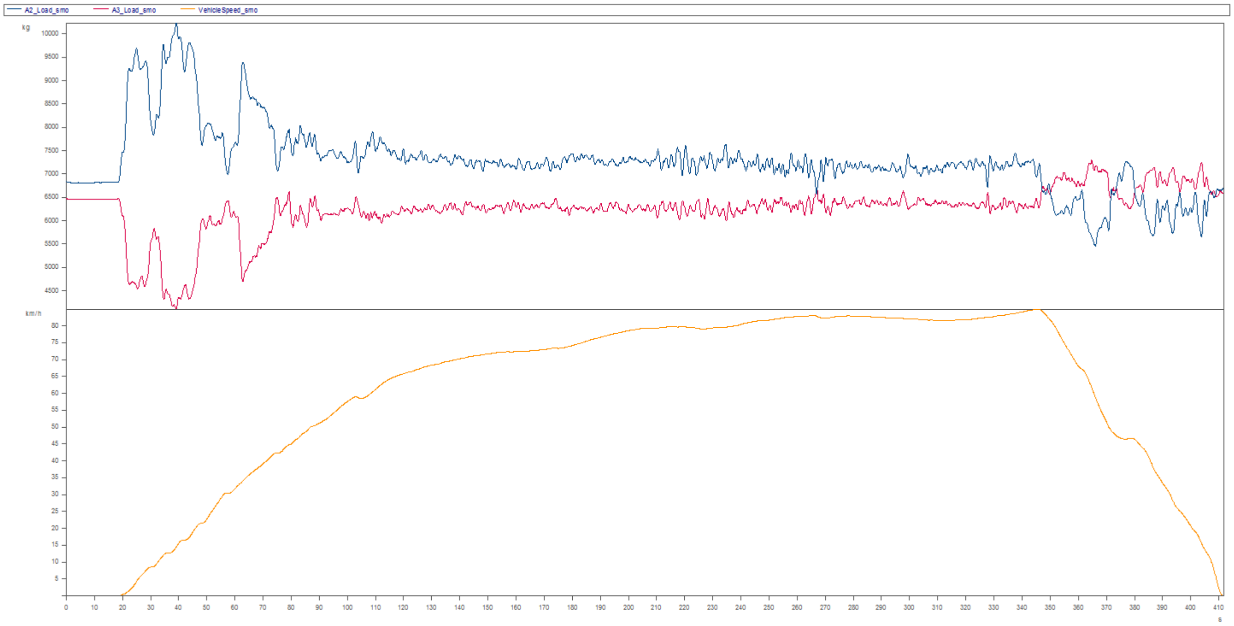

Figure 13: Tractor KB @70% Axle Load

Table 16: Static Axle Load, KB 70%

Axle 2	Axle 3
6588 kg	6593 kg

Figure 13 shows the time history of the axle load on tractor KB for the entire lap. The static load case was 70%. The difference in axle load at the start of the test is approximately 300 kg, with the drive axle slightly heavier. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). As the vehicle started on ice, the tractor's suspension controller immediately biased axle load to the drive axle due to wheel slip.

The programming of the suspension controller for vehicle KB is such that the drive axle is slightly biased with additional load for traction assist. There is no provision to force the system to equalize manually. Once the vehicle's control systems detect slip, the suspension controller reacts by rapidly evacuating the non-drive axle's air springs, which shifts the non-drive axle's load to the drive axle. In this particular case, the suspension controller appeared to attempt to return to an axle load distribution that more closely reflected the static condition each time when wheel slip subsided, but was prevented from doing so by the onset of more slip. The elapsed time for the initial load transfer was approximately four seconds.

As the vehicle gains speed and wheel slip is eliminated, the suspension controller slowly begins to equalize the axle loads but is interrupted on several occasions. In this test case, the time elapsed from the initial load transfer and when the axle load returns to a value more reflective of the quasi-static condition required approximately 60 seconds.

4.2.8 Tractor KB, 50% Load

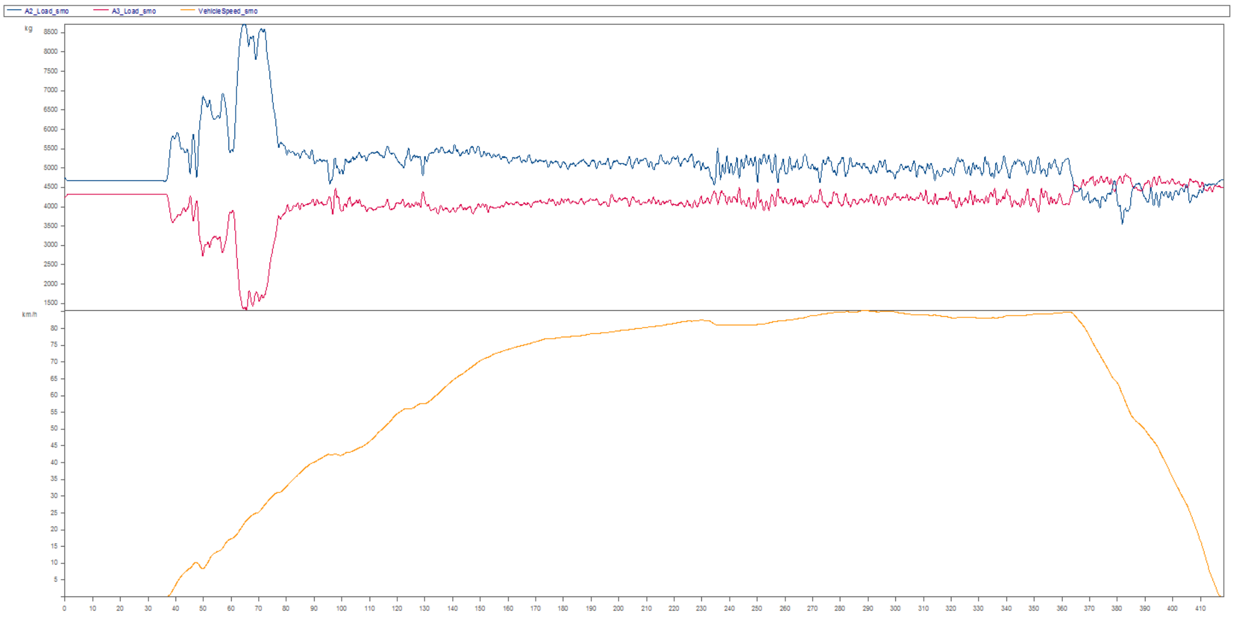

Figure 14: Tractor KB @50% Axle Load

Table 17: Static Axle Load, KB 50%

Axle 2	Axle 3
5500 kg	5072 kg

Figure 14 shows the time history of the axle load on tractor KB for the entire lap. The static load case was 50%. Table 17 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). As the vehicle started on ice, the tractor's suspension controller immediately biased axle load to the drive axle due to wheel slip.

The programming of the suspension controller for vehicle KB is such that the drive axle is slightly biased with additional load for traction assist. There is no provision to force the system to equalize manually. Once the vehicle's control systems detect slip, the suspension controller reacts by rapidly evacuating the non-drive axle's air springs, which shifts the non-drive axle's load to the drive axle. In this particular case, the suspension controller appeared to attempt to return to an axle load distribution that more closely reflected the static condition each time when wheel slip subsided, but was prevented from doing so by the onset of more slip. The elapsed time for the initial load transfer was approximately four seconds.

As the vehicle gains speed and wheel slip is eliminated, the suspension controller slowly begins to equalize the axle loads but is interrupted on several occasions. In this test case, the time elapsed from the initial load transfer and when the axle load returns to a value more reflective of the quasi-static condition required approximately 45 seconds.

4.2.9 Tractor KB, Empty

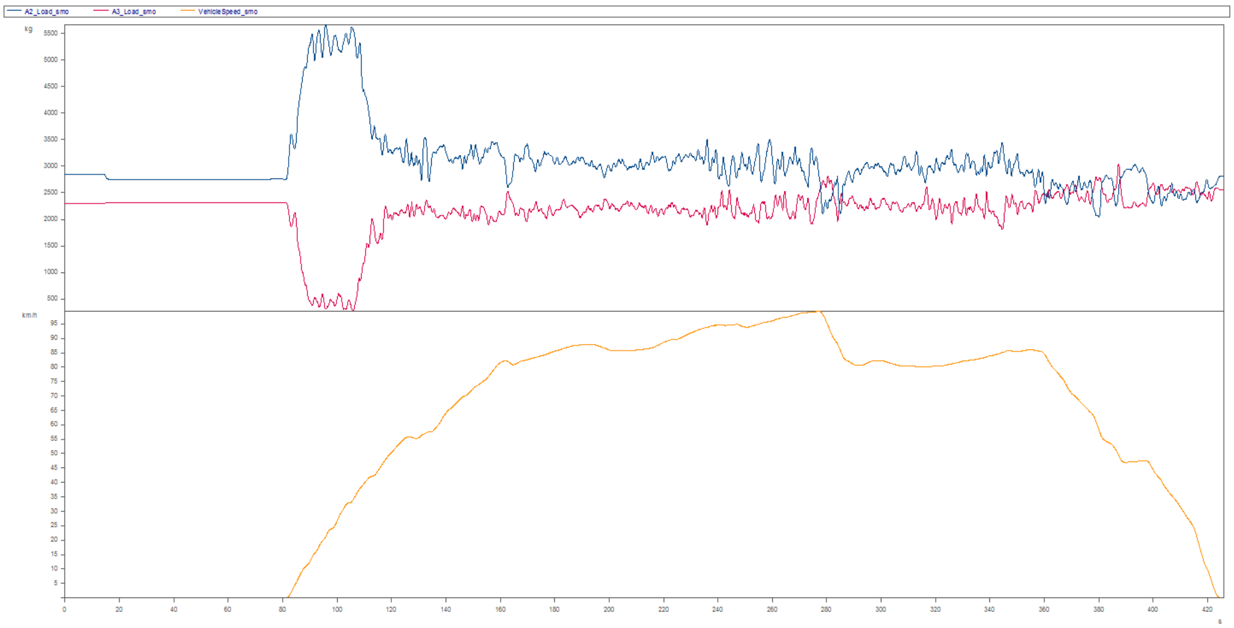

Figure 15: Tractor KB @0% Axle Load

Table 18: Static Axle Load, KB 0%

Axle 2	Axle 3
2755 kg	2311 kg

Figure 15 shows the time history of the axle load on tractor KB for the entire lap. The static load case was 0%. Table 18 lists the static axle load for reference. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). As the vehicle started on ice, the tractor's suspension controller immediately biased axle load to the drive axle due to wheel slip.

The programming of the suspension controller for vehicle KB is such that the drive axle is slightly biased with additional load for traction assist. There is no provision to force the system to equalize manually. Once the vehicle's control systems detect slip, the suspension controller reacts by rapidly evacuating the non-drive axle's air springs, which shifts the non-drive axle's load to the drive axle. The elapsed time for this event is approximately nine seconds.

As the vehicle gains speed and wheel slip is eliminated, the suspension controller slowly begins to equalize the axle loads. The equalization takes place over a period of approximately 16 seconds once slip has stopped.

4.2.10 Tractor VA, 100% Load

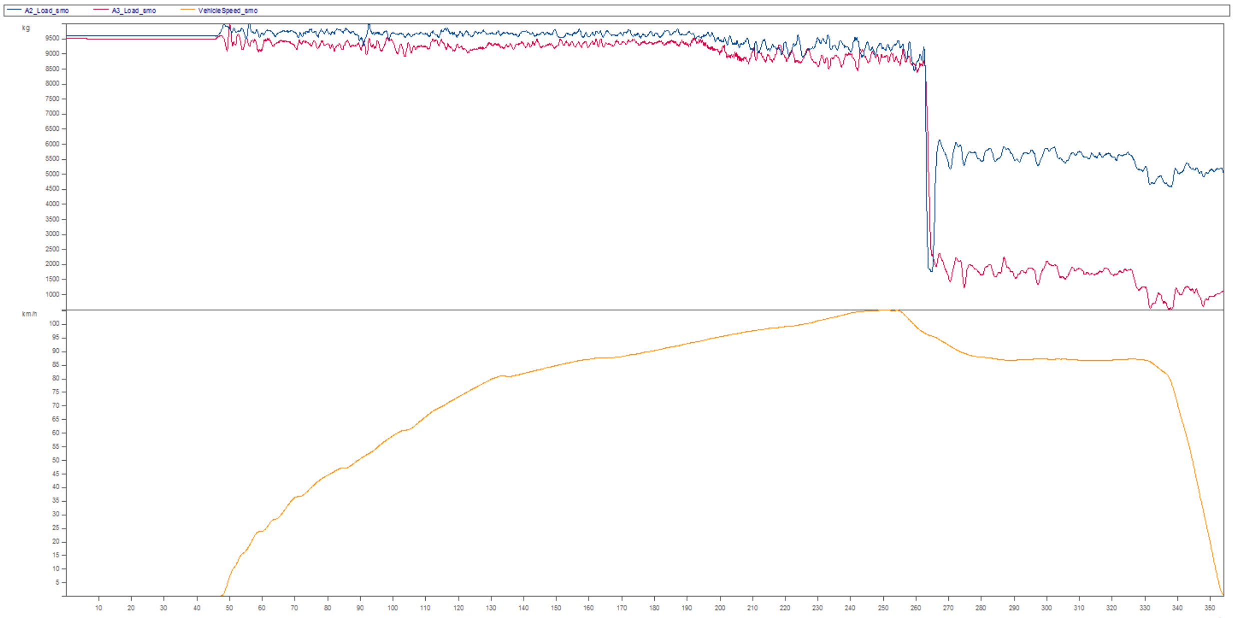

Figure 16: Tractor VA @100% Axle Load

Table 19: Static Axle Load, VA 100%

Axle 2	Axle 3
9996 kg	9935 kg

Figure 16 shows the time history of the axle load on tractor VA for the entire lap. The static load case was 100%. Table 19 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

The sudden drop near the end of run was due to equipment failure associated with the WFT equipment on the left side of the vehicle. Because this was one of the last runs of the entire test campaign and the failure occurred near the end of the lap, after an examination of the recorded data it was decided that a sufficient portion of the lap had been completed for the purposes of this test. If there was sufficient time remaining at the end of the test campaign, this test would be re-run.

4.2.11 Tractor VA, 85% Load

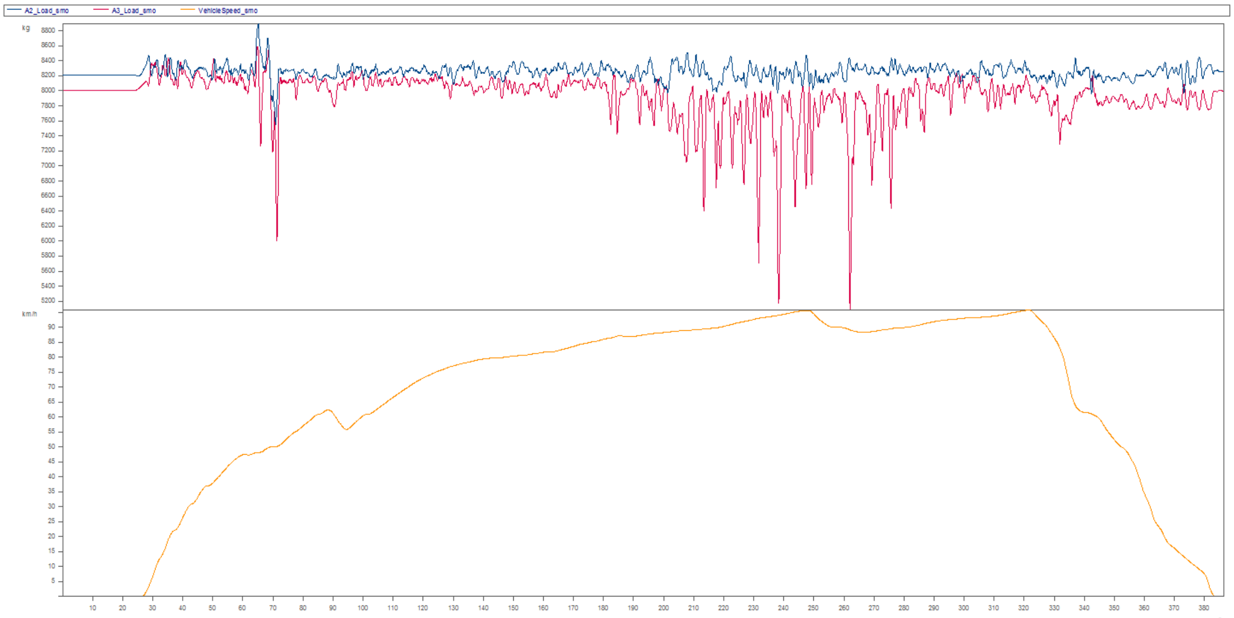

Figure 17: Tractor VA @85% Axle Load

Table 20: Static Axle Load, VA 85%

Axle 2	Axle 3
8223 kg	8179 kg

Figure 17 shows the time history of the axle load on tractor VA for the entire lap. The static load case was 85%. Table 20 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

The wild oscillations of the red trace were attributed to a faulty WFT cable. The cables had been damaged previously in the 100% lap and were field expediently repaired while awaiting proper replacements. While the large swings were not ideal, the overall record shows that the WFT was still operating correctly for the quasi-static axle load quantities. As tractor VA was the last vehicle to be tested and the test campaign itself was drawing to a close, it was decided that this data would be retained and if time permitted re-runs, this load case would also be re-run.

4.2.12 Tractor VA, 70% Load

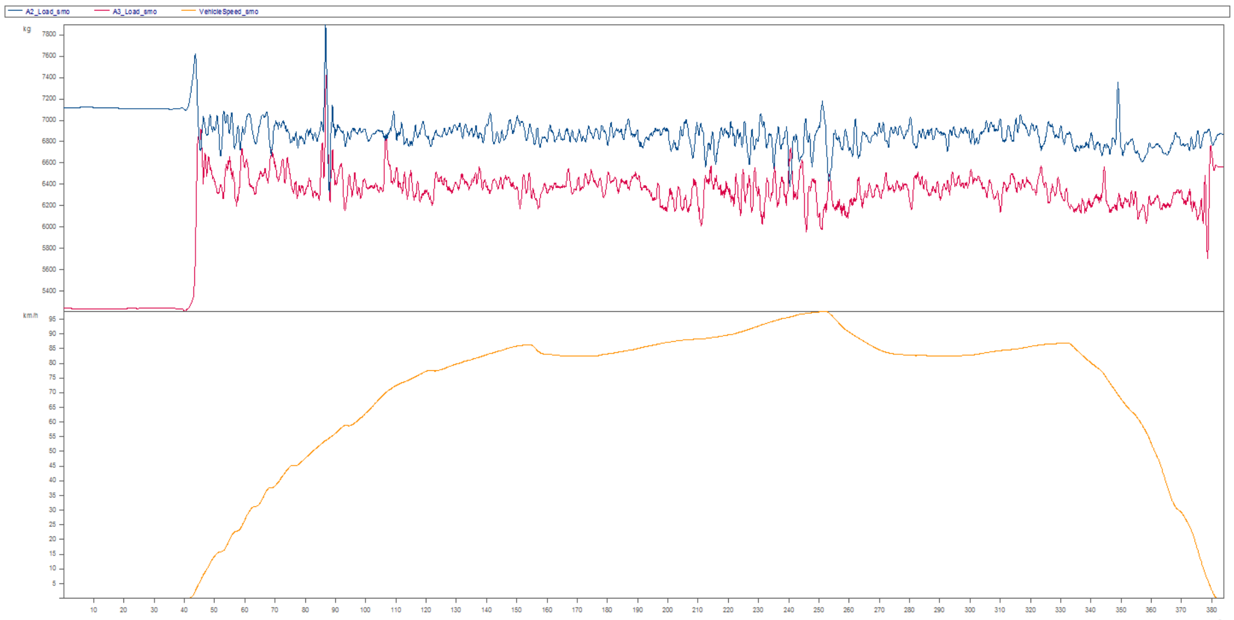

Figure 18: Tractor VA @70% Axle Load

Table 21: Static Axle Load, VA 70%

Axle 2	Axle 3
6638 kg	6573 kg

Figure 18 shows the time history of the axle load on tractor VA for the entire lap. The static load case was 70%. Table 21 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.13 Tractor VA, 50% Load

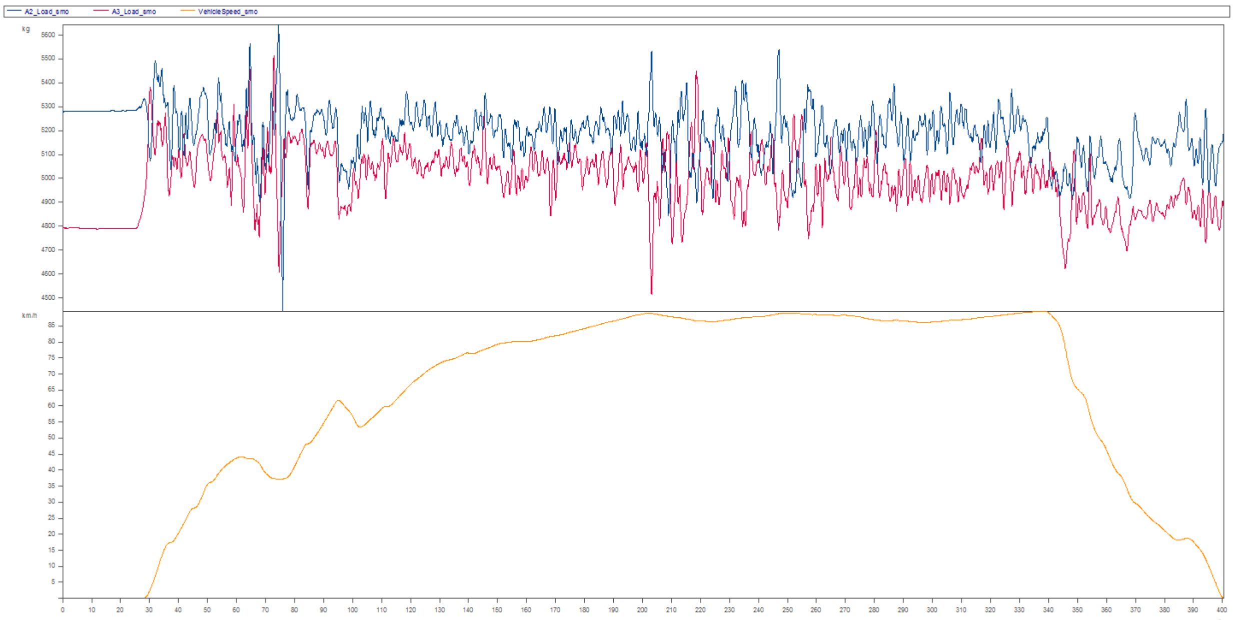

Figure 19: Tractor VA @50% Axle Load

Table 22: Static Axle Load, VA 50%

Axle 2	Axle 3
4903 kg	5034 kg

Figure 19 shows the time history of the axle load on tractor VA for the entire lap. The static load case was 50%. Table 22 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.14 Tractor VA, Empty

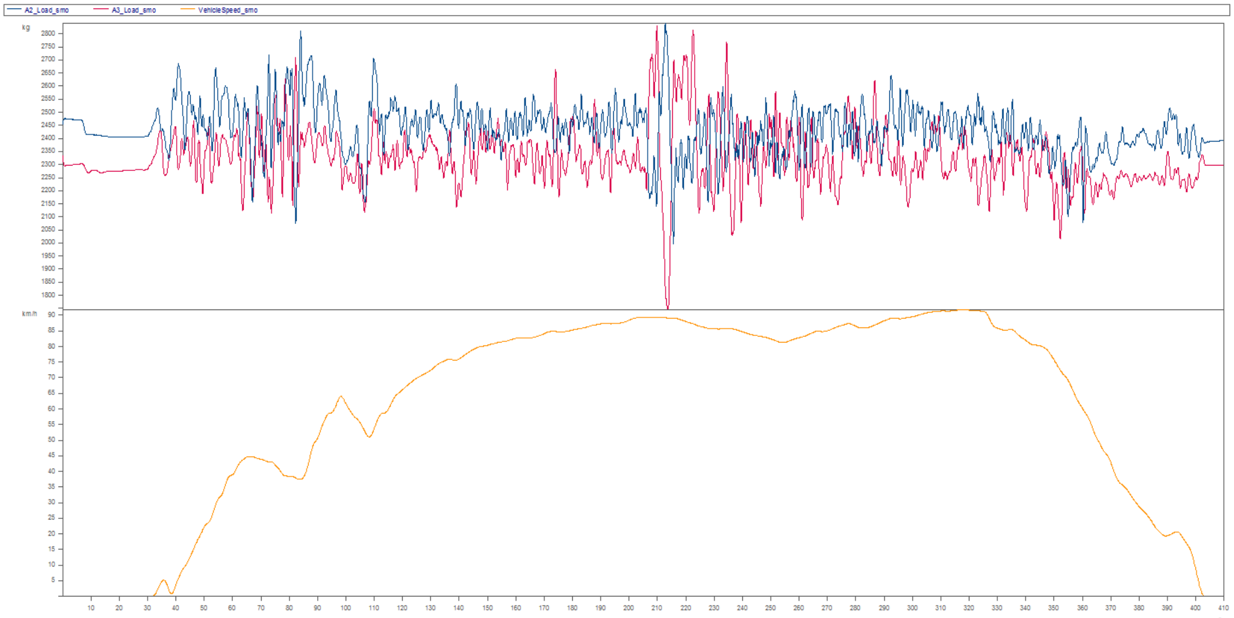

Figure 20: Tractor VA @0% Axle Load

Table 23: Static Axle Load, VA 0%

Axle 2	Axle 3
2408 kg	2280 kg

Figure 20 shows the time history of the axle load on tractor VA for the entire lap. The static load case was 0%. Table 23 lists the static axle load as ballasted for reference. Axle 1 is the steer axle and was not instrumented for load. Axle 2 is the middle axle, and axle 3 is the trailing axle. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.15 Tractor VB, 100% Load

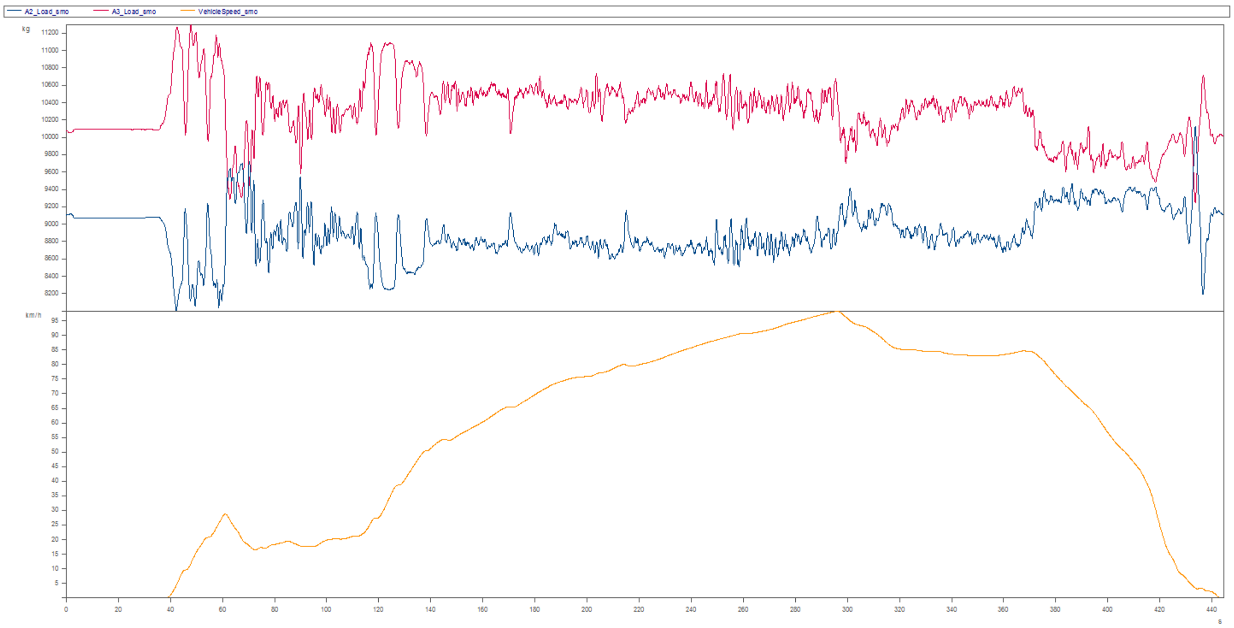

Figure 21: Tractor VB @100% Axle Load

Table 24: Static Axle Load, VB 100%

Axle 2	Axle 3
10150 kg	9951 kg

Figure 21 shows the time history of the axle load on tractor VB for the entire lap. The static load case was 100%. The bottom trace is vehicle speed, the top trace contains the middle (non-drive) axle load (blue), and the rear (drive) axle load (red).

4.2.16 Tractor VB, 85% Load

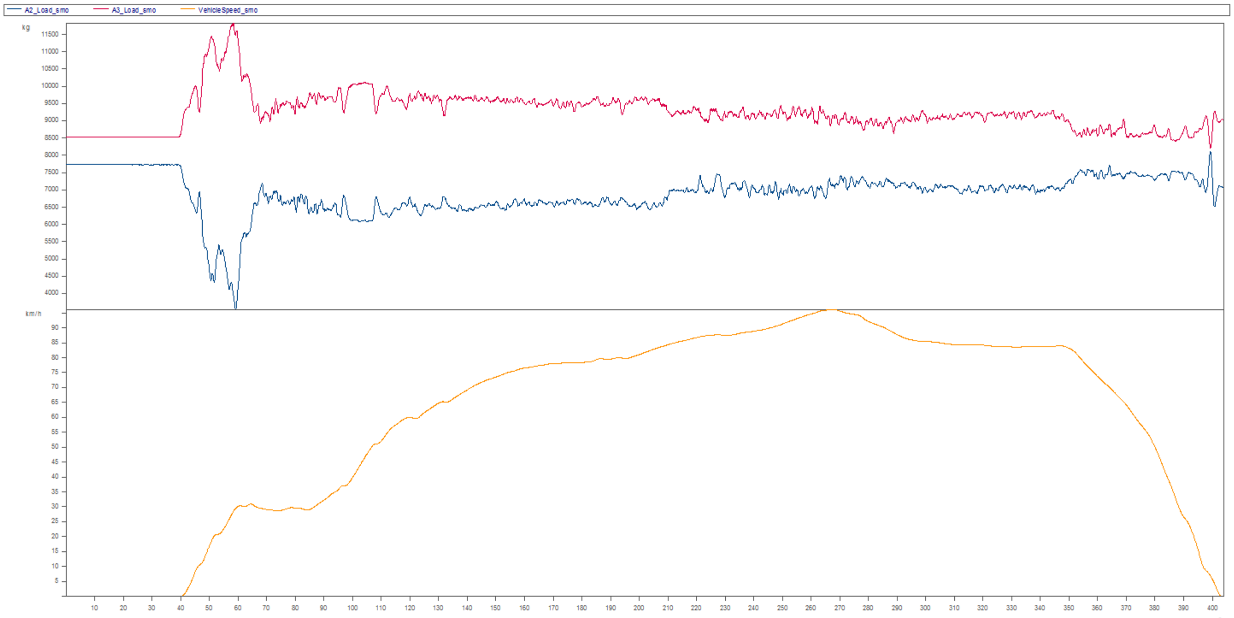

Figure 22: Tractor VB @85% Axle Load

Table 25: Static Axle Load, VB 85%

Axle 2	Axle 3
8381 kg	7954 kg

Figure 22 shows the time history of the axle load on tractor VB for the entire lap. The static load case was 85%. The bottom trace is vehicle speed, the top trace contains the middle (non-drive) axle load (blue), and the rear (drive) axle load (red).

4.2.17 Tractor VB, 70% Load

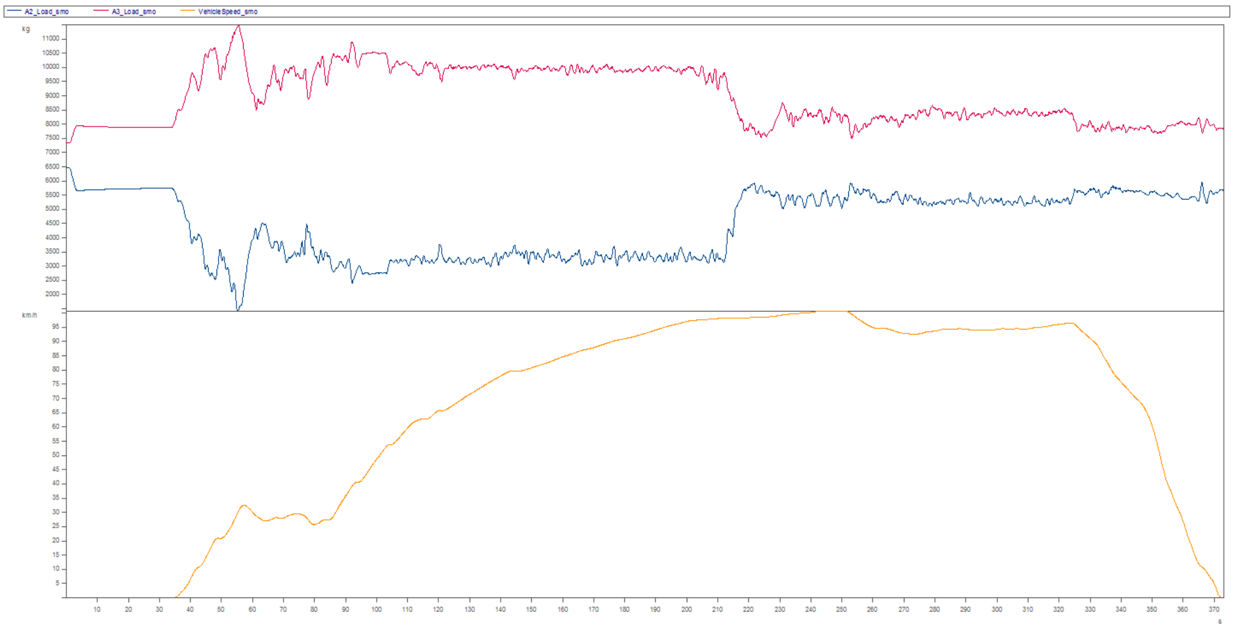

Figure 23: Tractor VB @70% Axle Load

Table 26: Static Axle Load, VB 70%

Axle 2	Axle 3
7051 kg	6915 kg

Figure 23 shows the time history of the axle load on tractor VB for the entire lap. The static load case was 70%. The bottom trace is vehicle speed, the top trace contains the middle (non-drive) axle load (blue), and the rear (drive) axle load (red).

4.2.18 Tractor VB, 50% Load

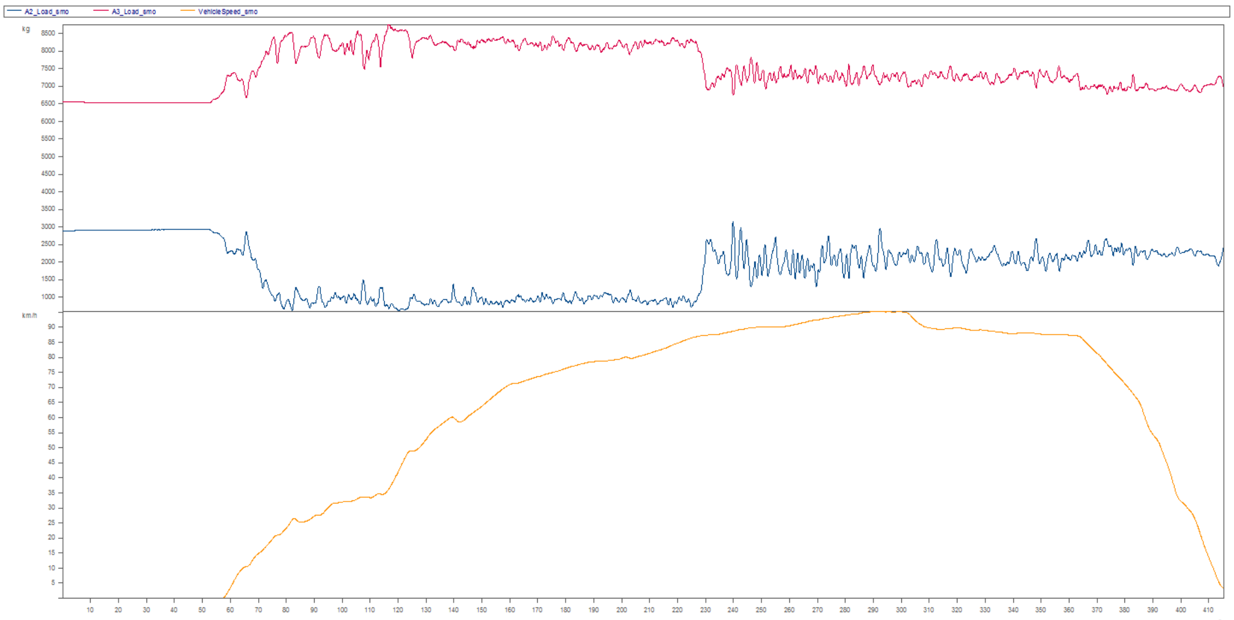

Figure 24: Tractor VB @50% Axle Load

Table 27: Static Axle Load, VB 50%

Axle 2	Axle 3
4603 kg	4909 kg

Figure 24 shows the time history of the axle load on tractor VB for the entire lap. The static load case was 50%. The bottom trace is vehicle speed, the top trace contains the middle (non-drive) axle load (blue), and the rear (drive) axle load (red).

4.2.19 Tractor VB, Empty

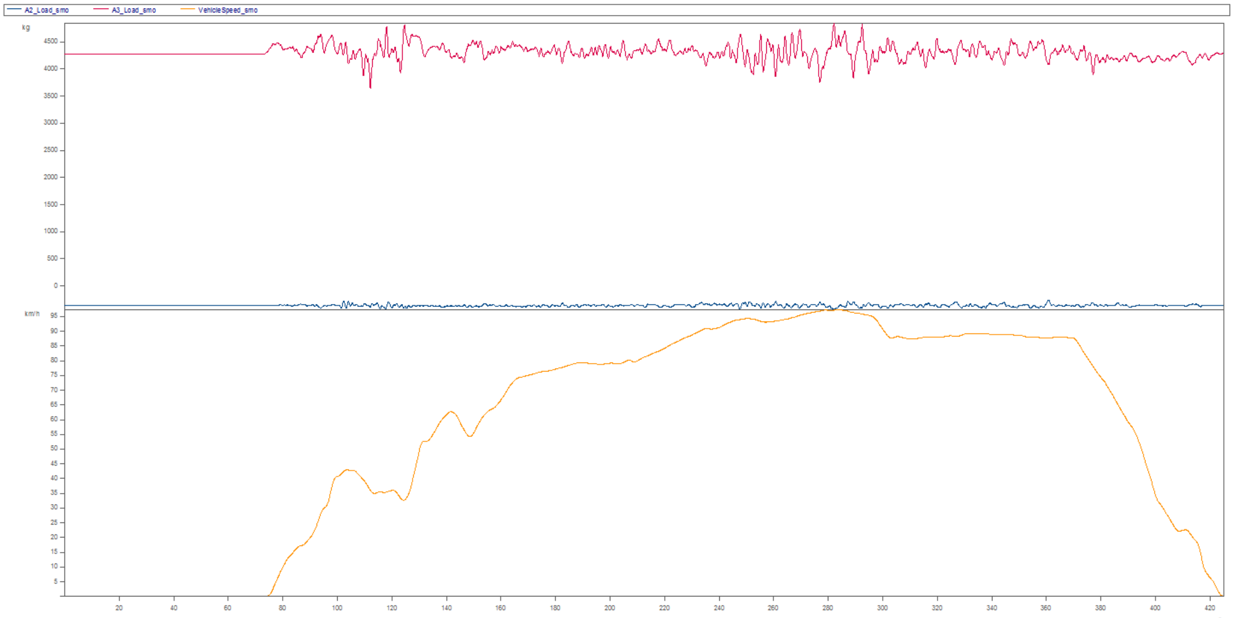

Figure 25: Tractor VB @0% Axle Load

Table 28: Static Axle Load, VB 0%

Axle 2	Axle 3
2311 kg	2192 kg

Figure 25 shows the time history of the axle load on tractor VB for the entire lap. The static load case was 0% (empty trailer). The bottom trace is vehicle speed, the top trace contains the middle (non-drive) axle load (blue), and the rear (drive) axle load (red).

The programming of the suspension controller for vehicle VB is such that the drive axle is preferentially biased with as much load as possible (without exceeding a programmed maximum) for optimized traction. There is an operator provision to force the system to equalize manually for activities such as when un/loading an attached trailer, as recommended by the manufacturer. Table 28 shows static axle load for reference with the axles equalized.

For the 0% load lap, the non-drive axle is physically lifted and is not in contact with the ground at any time. The blue trace shows a relatively small negative value, which corresponds to the dead weight of the tire/wheel assembly as it is suspended by the axle.

4.2.20 Tractor FA, 100% Load

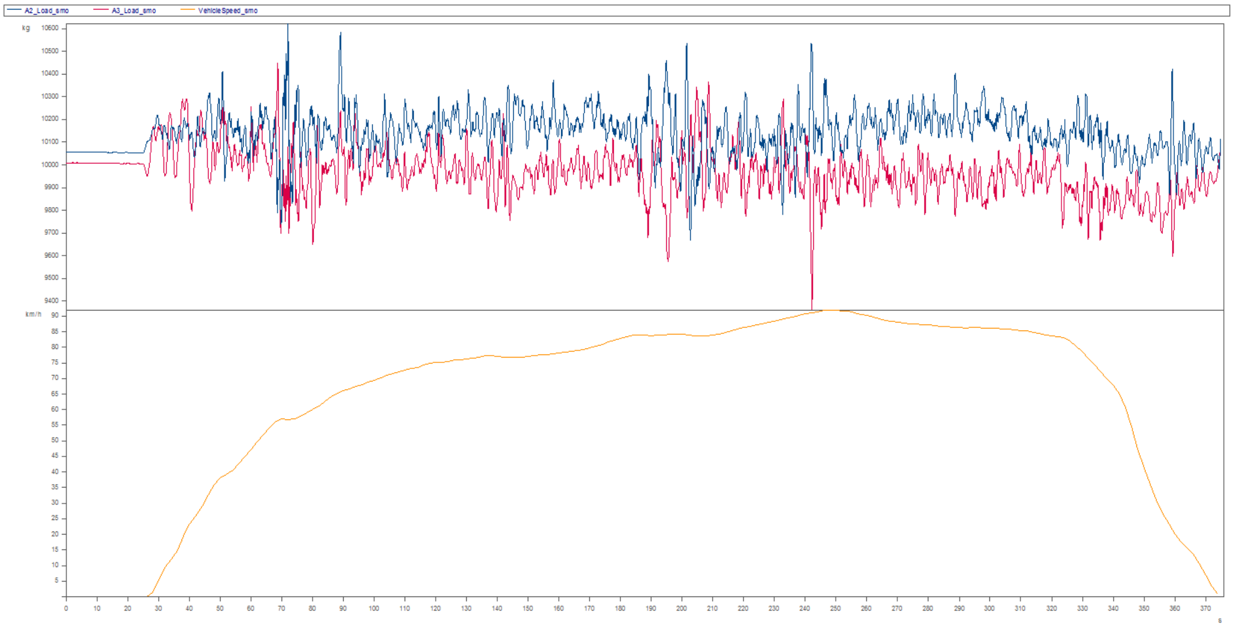

Figure 26: Tractor FA @100% Axle Load

Table 29: Static Axle Load, FA 100%

Axle 2	Axle 3
10052 kg	9924 kg

Figure 26 shows the time history of the axle load on tractor FA for the entire lap. The static load case was 100%. Table 29 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.21 Tractor FA, 85% Load

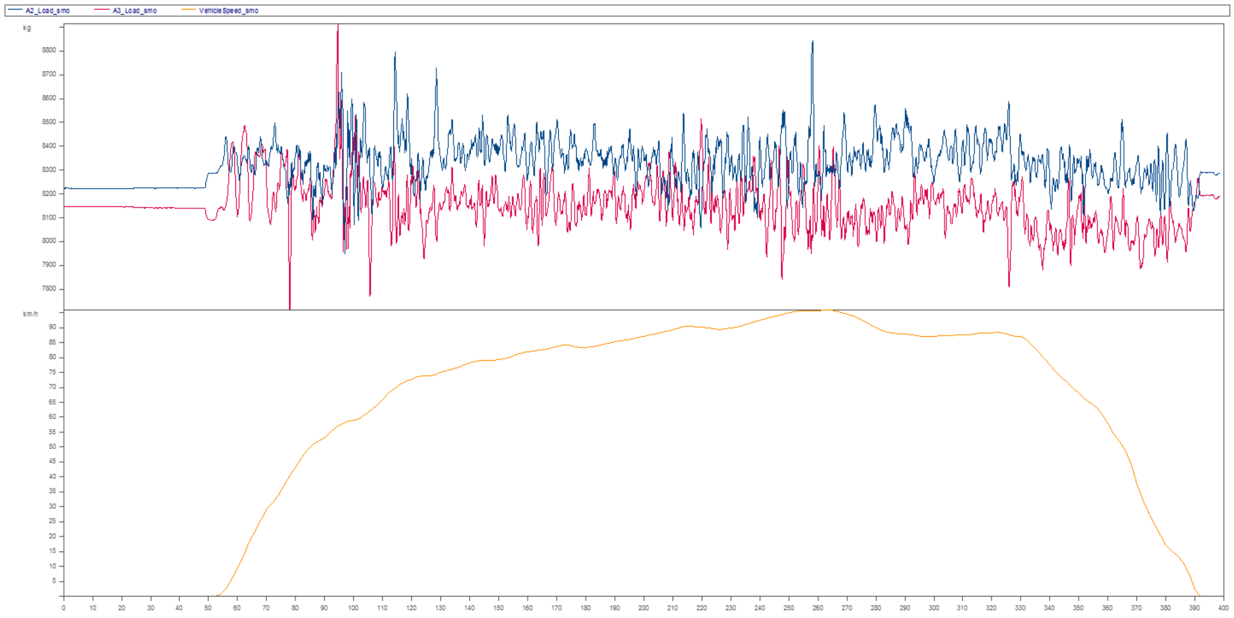

Figure 27: Tractor FA @85% Axle Load

Table 30: Static Axle Load, FA 85%

Axle 2	Axle 3
8241 kg	8202 kg

Figure 27 shows the time history of the axle load on tractor FA for the entire lap. The static load case was 85%. Table 30 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.22 Tractor FA, 70% Load

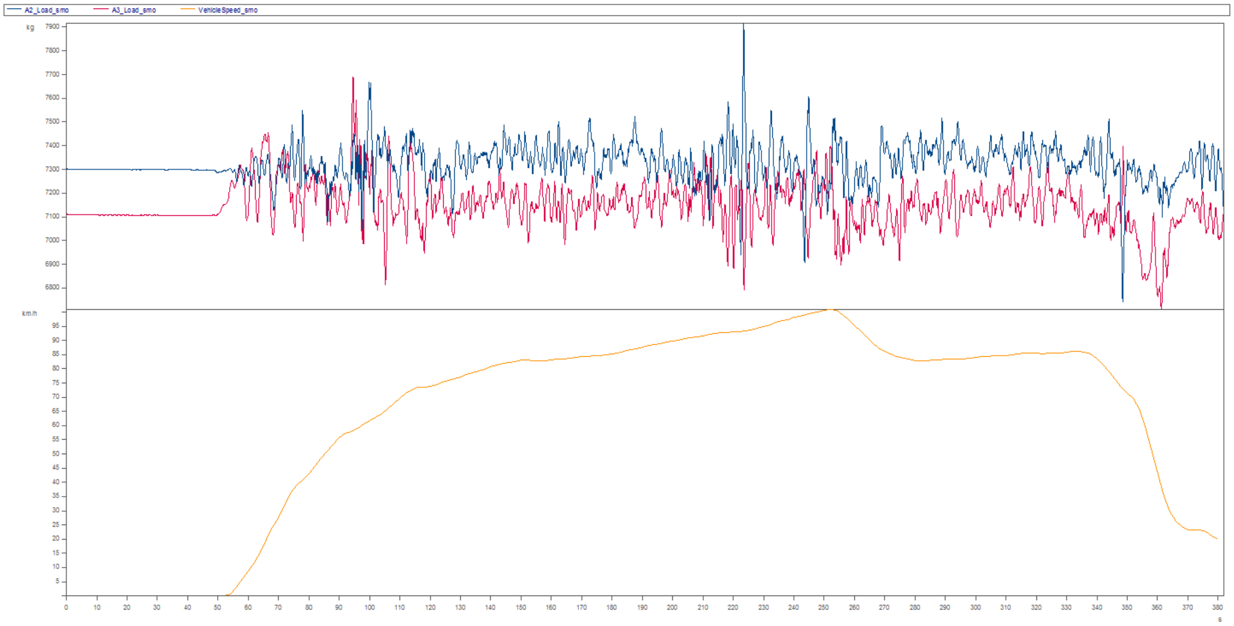

Figure 28: Tractor FA @70% Axle Load

Table 31: Static Axle Load, FA 70%

Axle 2	Axle 3
7195 kg	7137 kg

Figure 28 shows the time history of the axle load on tractor FA for the entire lap. The static load case was 70%. Table 31 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.23 Tractor FA, 50% Load

Figure 29: Tractor FA @50% Axle Load

Table 32: Static Axle Load, FA 50%

Axle 2	Axle 3
5116 kg	4971 kg

Figure 29 shows the time history of the axle load on tractor FA for the entire lap. The static load case was 50%. Table 32 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.24 Tractor FA, Empty

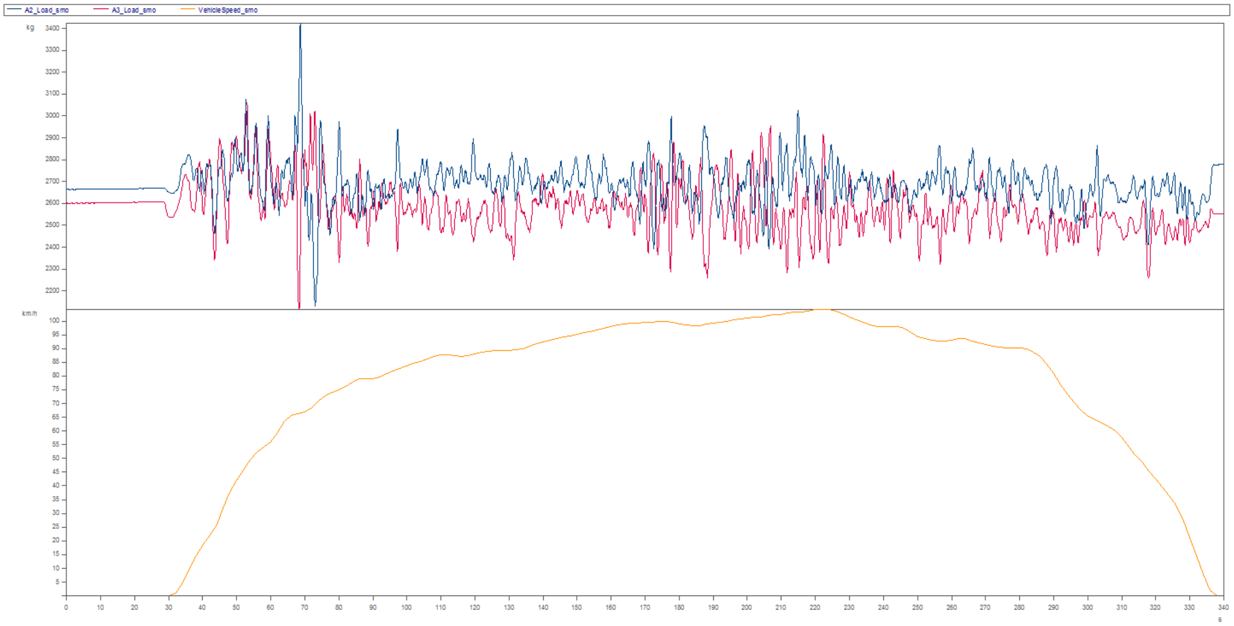

Figure 30: Tractor FA @0% Axle Load

Table 33: Static Axle Load, FA 0%

Axle 2	Axle 3
2666 kg	2603 kg

Figure 30 shows the time history of the axle load on tractor FA for the entire lap. The static load case was 0%. Table 33 lists the static axle load as ballasted for reference. The bottom trace is vehicle speed, the top trace contains the two drive axle loads (middle: blue, rear: red). Even though the vehicle started on ice, the tractor's suspension controller maintains equalized axle load regardless of wheel slip.

4.2.25 Tractor FB, 100% Load

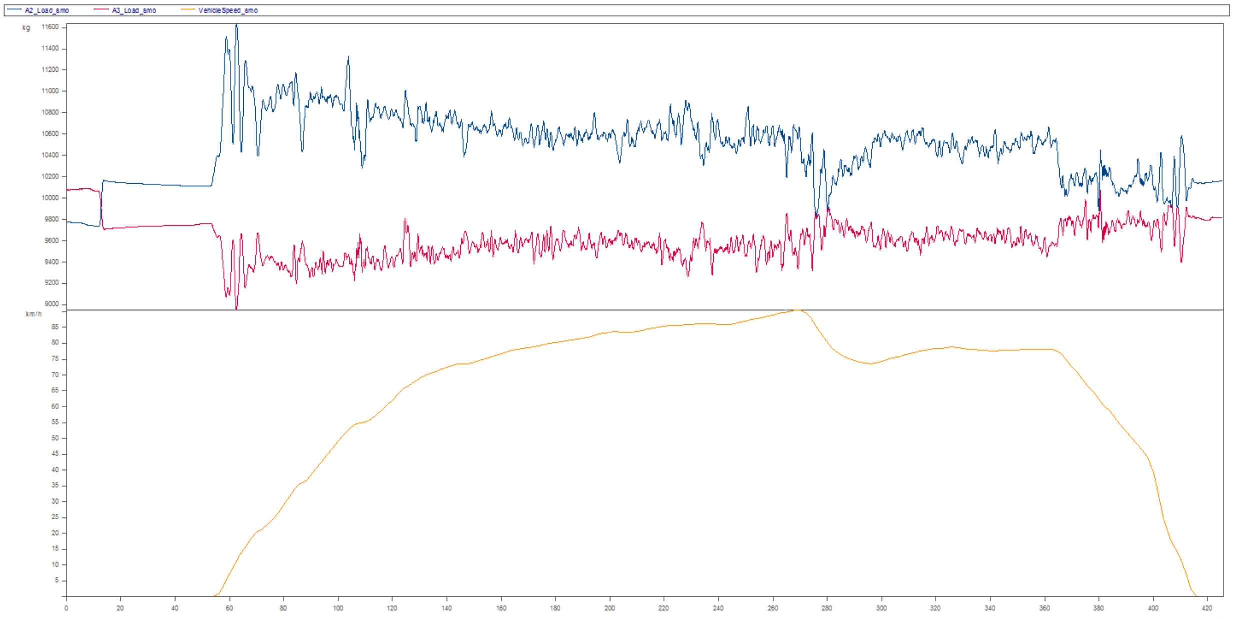

Figure 31: Tractor FB @100% Axle Load

Table 34: Static Axle Load, FB 100%

Axle 2	Axle 3
10082 kg	9983 kg

Figure 31 shows the time history of the axle load on tractor FB for the entire lap. The static load case was 100%. Table 34 shows the static axle loads for reference. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). Though the two load traces appear to be different, they are actually within 100 kg of each other when the vehicle is stationary.

For the 100% load condition, there is very little headroom for the suspension controller to pre-emptively bias the drive axle for traction assist and the indicator lamp in the instrument panel is not lit, indicating that the system is in equalized mode. However, during acceleration when slip is detected, the suspension controller attempts to shift load to the drive axle, but the effect is not as pronounced as with lighter axle loads. Relative to the lighter loads (70% and below), the axle controller appears to be "hunting", alternating between traction assist and equalizing.

4.2.26 Tractor FB, 85% Load

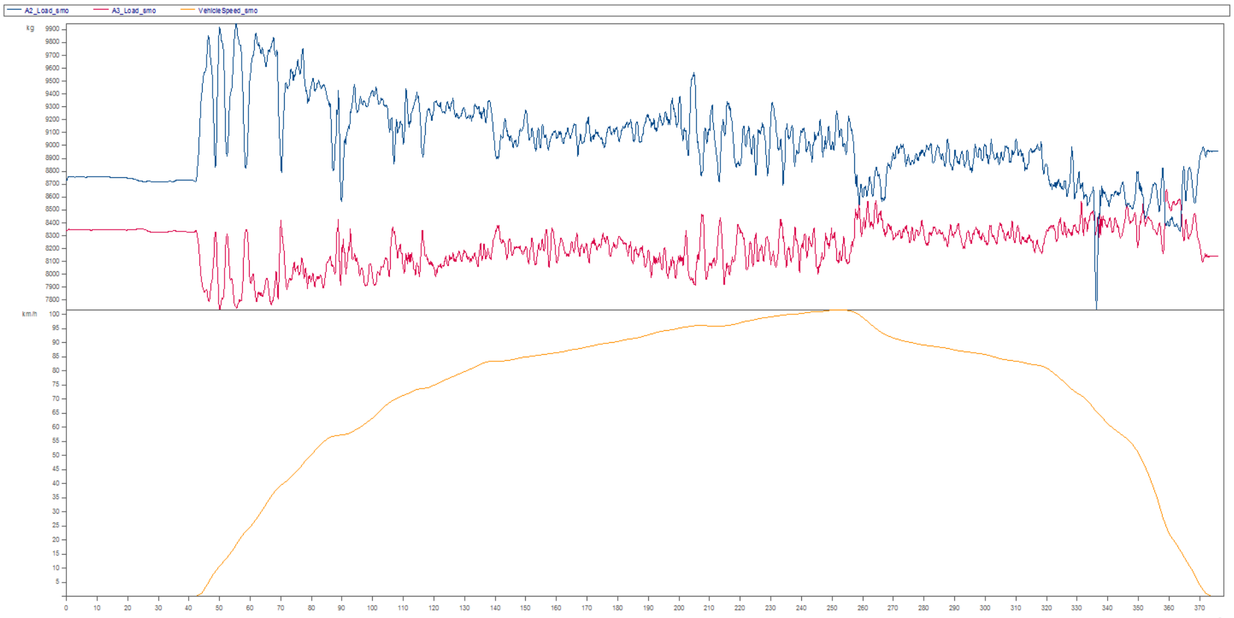

Figure 32: Tractor FB @85% Axle Load

Table 35: Static Axle Load, FB 85%

Axle 2	Axle 3
8616 kg	8385 kg

Figure 32 shows the time history of the axle load on tractor FB for the entire lap. The static load case was 85%. Table 35 shows the static axle loads for reference. The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). The programming of the suspension controller for vehicle FB is such that the drive axle is pre-emptively biased with additional load for traction assist and an indicator lamp in the instrument panel indicates this function is enabled.

For the 85% load condition, the suspension controller is only able to pre-emptively bias the drive axle for traction assist slightly, and the indicator lamp in the instrument panel is lit, indicating that the system is in traction assist mode, but the effect is not as pronounced as with lighter axle loads. Relative to the lighter loads (70% and below), the axle controller appears to be "hunting", alternating between traction assist and equalizing.

There is no provision to force the system to equalize manually. The manufacturer’s literature states that the pre-load is cancelled when the vehicle’s speed exceeds 72 km/h and the axle load returns to equalized. The recorded data strongly indicates that the axle load control operates as claimed. The time required for vehicle FB to transition from biased to equalized is between three to five seconds.

4.2.27 Tractor FB, 70% Load

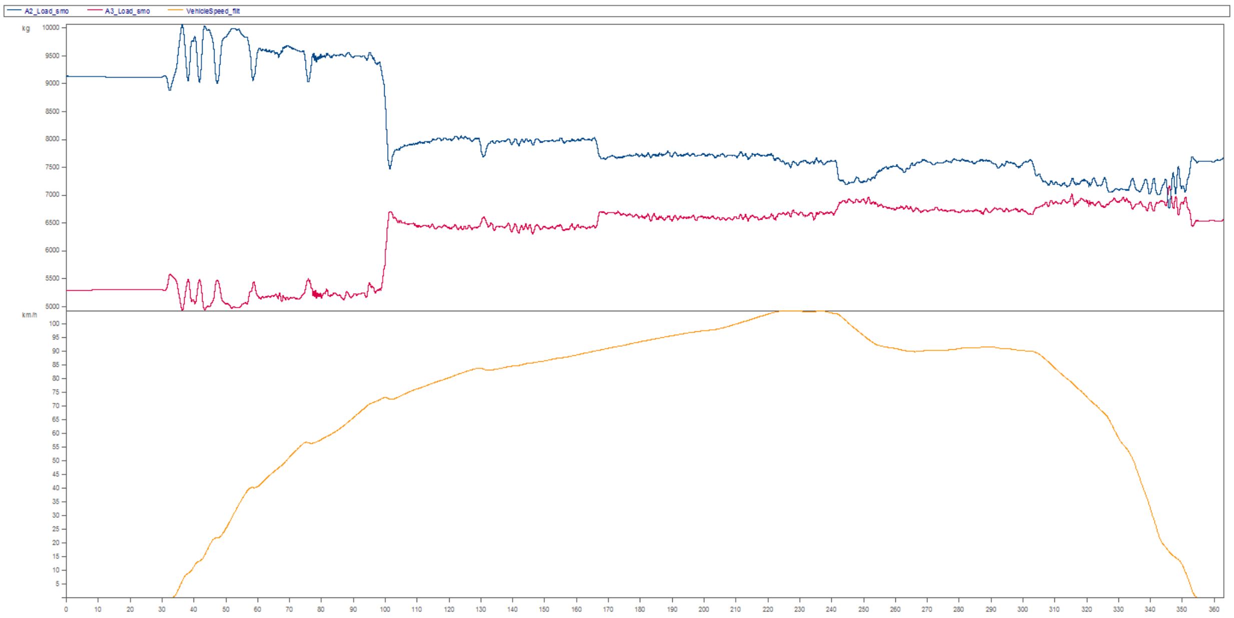

Figure 33: Tractor FB @70% Axle Load

Table 36: Static Axle Load, FB 70%

Axle 2	Axle 3
7138 kg	6862 kg

Figure 33 shows the time history of the axle load on tractor FB for the entire lap. The static load case was 70%.The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). The programming of the suspension controller for vehicle FB is such that the drive axle is pre-emptively biased with additional load for traction assist and an indicator lamp in the instrument panel indicates this function is enabled.

There is no provision to force the system to equalize manually. The manufacturer's literature states that the pre-load is cancelled when the vehicle's speed exceeds 72 km/h and the axle load returns to equalized. The recorded data strongly indicates that the axle load control operates as claimed. The time required for vehicle FB to transition from biased to equalized is between three to five seconds.

4.2.28 Tractor FB, 50% Load

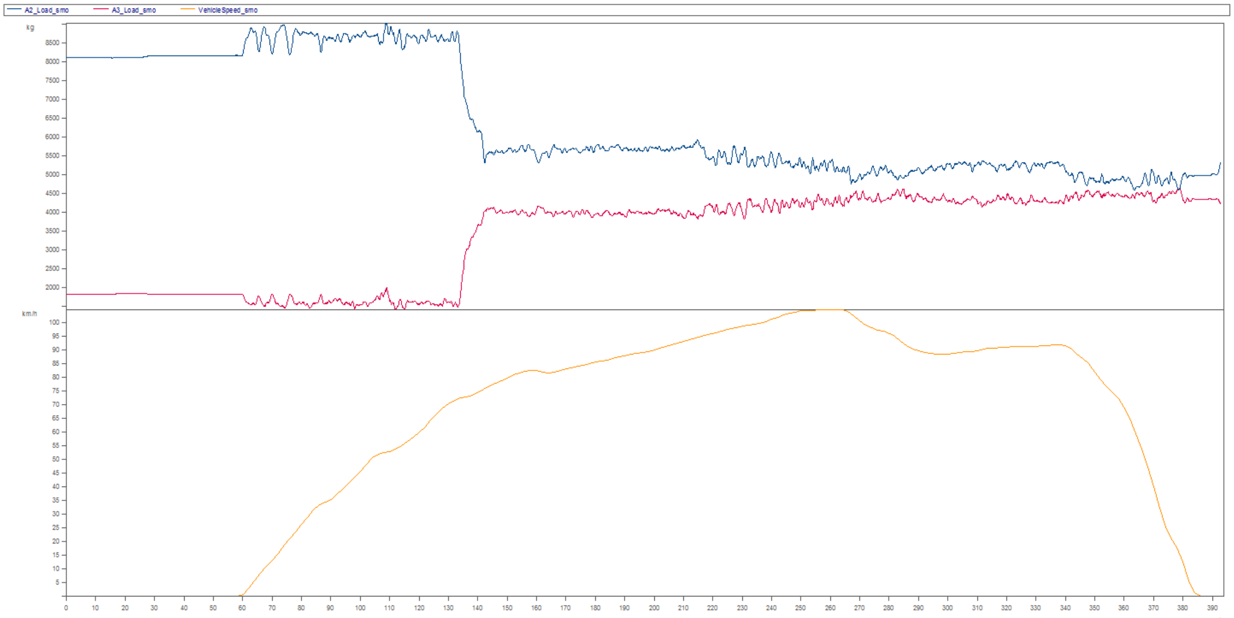

Figure 34: Tractor FB @50% Axle Load

Table 37: Static Axle Load, FB 50%

Axle 2	Axle 3
6234 kg	3370 kg

Figure 34 shows the time history of the axle load on tractor FB for the entire lap. The static load case was 50%.The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). The programming of the suspension controller for vehicle FB is such that the drive axle is pre-emptively biased with additional load for traction assist and an indicator lamp in the instrument panel indicates this function is enabled.

There is no provision to force the system to equalize manually. The manufacturer’s literature states that the pre-load is cancelled when the vehicle’s speed exceeds 72 km/h and the axle load returns to equalized. The recorded data strongly indicates that the axle load control operates as claimed. The time required for vehicle FB to transition from biased to equalized is between three to five seconds.

4.2.29 Tractor FB, Empty

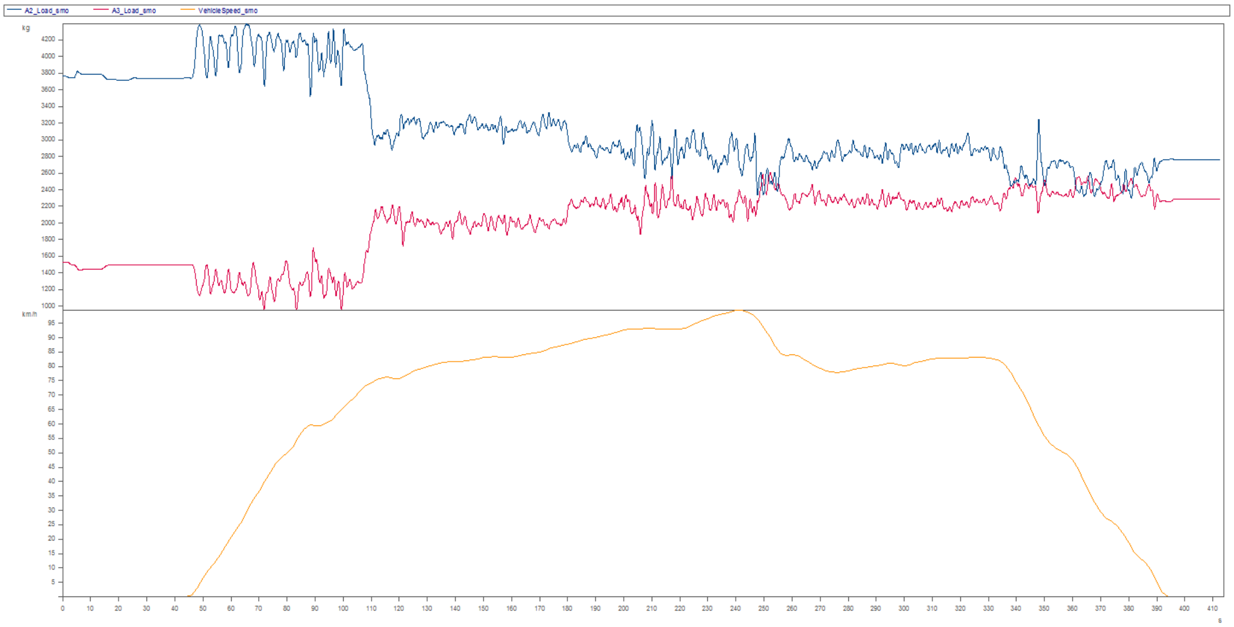

Figure 35: Tractor FB @0% Axle Load

Table 38: Static Axle Load, FB 0%

Axle 2	Axle 3
3733 kg	1497 kg

Figure 35 shows the time history of the axle load on tractor FB for the entire lap. The static load case was 0%.The bottom trace is vehicle speed, the top trace contains the middle (drive) axle load (blue), and the rear (non-drive) axle load (red). The programming of the suspension controller for vehicle FB is such that the drive axle is pre-emptively biased with additional load for traction assist and an indicator lamp in the instrument panel indicates this function is enabled.

There is no provision to force the system to equalize manually. The manufacturer's literature states that the pre-load is cancelled when the vehicle's speed exceeds 72 km/h and the axle load returns to equalized. The recorded data strongly indicates that the axle load control operates as claimed. The time required for vehicle FB to transition from biased to equalized is between three to five seconds.

5 DISCUSSION

Tractor VB is able to physically lift the non-drive axle in cases of light loads often encountered with empty trailers or with no trailer attached. By raising the non-drive axle, lower wear on the running components (brakes, tires, bearings, etc.) can be realized. The tractor also gains slightly improved driveability/maneuverability with the non-drive axle raised as tire scrub is eliminated during turning.

According to the manufacturer, the system equipped on tractor VB is optimized for operators that encounter empty/light loads for a large portion of their operations and is not necessarily a good fit for traditional long-haul service. Operations that could benefit from the system implemented on tractor VB include bulk haul (tanker or commodity), flatbed services, declining loads (pickup & delivery), and other similar types of operations where one or more legs is with no load or no trailer.

In all cases, the 6x2 control strategies are tunable based on their calibration settings during their respective development cycles. One possibility of easing concerns of regulators and infrastructure planners may be to augment the on-board 6x2 control systems with additional information from vehicle-to-infrastructure (V2I) communications, geofencing, and other Intelligent Transportation Systems (ITS) technologies.

Such technologies would potentially allow cities, provinces, and other authorities to create carve-outs in areas where the traction help load-shifting technologies could and could not operate, as well as potentially limit the magnitude and duration of these load-shift events. This could be especially helpful around specific items of interest such as bridges, as well as seasonal restrictions.

Any developments in the ITS space, especially those involving V2I communications, should be taken in cooperation with the various OEM's. Their (the OEM's) participation in pilot studies and demonstrators should be solicited early in the investigative process.

6 CONCLUSIONS

All of the tested 6x4 tractors (KA, VA, FA) maintained axle loading as equally as possible at all times. All the tested 6x2 systems exhibited behaviour that were in line with expectations based on their respective OEM's published claims.

The system installed on tractor KB appeared to have the greatest variability in terms of response based on axle load. This system as programmed attempts to maintain an equal axle loading under normal conditions and only biases the drive axle when slip is detected. However this only applies up to moderate loads. As the axle load increases, the drive axle load appears to be limited to ~7400 kg, with balance on the non-drive axle. It is unclear if this is deliberate.

Tractor VB appears to preferentially bias the drive axle with as much load as possible, and shifts the balance to the non-drive axle only when necessary. When empty, the non-drive axle is lifted free of ground contact and the vehicle operates as a 4x2 drive tractor. This correlates well with manufacturer's claims regarding its operation.

Tractor FB represents a blend of the systems implemented on tractors KB and VB. Like tractor VB, the drive axle is preferentially biases the drive axle for traction assist. As the vehicle speed exceeds the transition speed, tractor FB adopts the equalized characteristics of tractor KB.

ACRONYMS, ABBREVIATIONS, AND UNITS

Acronyms and Abbreviations

AST	Automotive and Surface Transportation
CAN	Controller Area Network
IBC	Intermediate Bulk Container
GPS	Global Positioning System
IMU	Inertial Measurement Unit
ITS	Intelligent Transportation Systems
NRC	National Research Council Canada
RPY	Roll, Pitch, Yaw
TCS	Traction Control System
V2I	Vehicle-to-Infrastructure
WFT	Wheel Force Transducer

Units and Symbols

Hz	Hertz
kg	kilogram(s)
L	litre(s)

a_x	longitudinal acceleration
a_y	lateral acceleration
a_z	vertical acceleration
F_x	longitudinal force
F_y	lateral force
F_z	vertical force
M_x	roll moment
M_y	pitch moment
M_z	yaw moment
ϕ_x'	roll rate
θ_y'	pitch rate
ψ_z'	yaw rate
θ	angular position
ω	angular velocity