

Development of regulatory principles for straight trucks and truck – trailer combinations

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This paper describes how regulatory principles were developed to add straight trucks and truck trailer combinations to Canada's Memorandum of Understanding on Vehicle Weights and Dimensions. It describes the vehicles studied, the dynamic analysis methods, and the results and conclusions. It briefly describes some full-scale tests, and shows correlations between test and the computer simulation. Finally, it summarizes the principles that will be the basis for regulation of straight trucks and truck-trailer combinations in Canada.

1/ INTRODUCTION

Canada's ten provinces and two territories are each responsible for highway transportation in their own jurisdiction, so Canada has developed twelve somewhat distinct sets of truck weight and dimension regulations. The most recent major step in an ongoing process to establish uniformity in these regulations was the Vehicle Weights and Dimensions Study, whose technical phase concluded in 1986 [1,2,3]. Regulatory principles were proposed, based on the dynamic performance of vehicles within the highway system. This became the basis for a Memorandum of Understanding (M.o.U.) between all jurisdictions [4], that set uniform configuration, weight and dimension rules for the principal vehicles used in inter-provincial trucking, tractor-semitrailers and A-, B- and C-train double trailer combinations.

While amending regulations to implement the M.o.U., it became apparent to many jurisdictions that trucks of all configurations, not just those covered by the M.o.U., should be regulated using the same performance standards. The principal configurations not covered by the M.o.U. were straight trucks and truck-trailer combinations. Ontario Ministry of Transportation was asked to undertake a study of these, to provide a technical basis for regulatory principles so that appropriate classes of vehicle could be added to the M.o.U. [5]. Many of the trucks already operating, such as those with liftable or self-steering axles, could not meet basic conditions of the M.o.U., so the study should also provide guidance for jurisdictions allowing such trucks to regulate them.

Straight trucks and truck-trailer combinations tend to be local-use vehicles that lack the unifying effect on configuration that arises when vehicles must be designed to operate in many jurisdictions. The first part of this study identified a large number of basic configurations that operated and were important in one or more jurisdictions. Many more exist, or could exist, under existing regulations. A technical study of the stability and control characteristics of these basic configurations was conducted, including variation of important parameters. The study was supported by a brief field test to demonstrate the sensitivity of dynamic performance to significant dimensional parameters. The study did not address pavement or bridge loading issues, as the M.o.U. already provided the appropriate constraints.

This paper presents briefly the methodology and results of the technical study, illustrates the test results, and summarizes discussions and conclusions of the regulatory development process.

2/ STUDY METHODOLOGY

2.1/ Computer Simulation

Stability and control performance was evaluated using Ontario Ministry of Transportation's personal computer version of the yaw/roll program [6]. This program integrates the Euler equations of motion of a multiply articulated truck composed of up to six vehicle units and eleven axles, driving at constant speed and subject either to a prescribed steer input, or using a driver model to follow a prescribed path. A sprung mass has five degrees of freedom, and an axle has two degrees of freedom. Five types of hitch can produce various articulations. Tires, suspension and self-steering axle properties are described by non-linear look-up tables. The program couples lateral/directional and roll responses of the vehicle. It has been used extensively in previous studies [1,7], and has been shown to agree adequately with tests for a wide range of truck configurations [8].

Vehicle data were obtained from manufacturers and operators, and by measurement of several hundred trucks at a truck inspection station. Component properties were based on data produced during the Weights and Dimensions Study [9]. The properties of three typical tires were measured.

The truck configurations in this study are widely used by the construction industries. Aggregate with a density of 2242 kg/cu m (140 lb/cu ft) was selected as a representative payload, distributed in such a way that assigned axle loads were attained.

Eight measures were used to characterize vehicle performance, though not all of them were necessarily significant for each vehicle configuration. The measures were based on definitions and standards developed for the Weights and Dimensions Study [2,9], and subsequent work [7]. The measures were generated by three manoeuvres, each defined by a path that the vehicle followed by means of the driver model.

Three measures were obtained from a high-speed turn made at 100 km/h, where the truck made a spiral entry into a curve of 0.2 g lateral acceleration, drove

along the curve for 10 s, then tightened the turn with a steering wheel steer rate of 2 deg/s until loss of control occurred :

Static roll threshold is the lateral acceleration of the power unit at which a roll-coupled unit of the truck just rolls over. It should exceed 0.4 g.

High-speed offtracking is the lateral offset from the path of the steer axle of the power unit to the path of the rearmost axle of the truck at 0.2 g lateral acceleration. It should not exceed 0.46 m outwards.

Understeer coefficient is a measure of how aggressively a truck responds to steering at 0.25 g lateral acceleration.

Two measures were obtained from a high-speed evasive manoeuvre of one cycle of sinusoidal lateral acceleration of 0.15 g at the power unit, made at 100 km/h, which gives a sidestep of 2.11 m :

Load transfer ratio is the fractional change in load between left- and right-hand side tires of the rearmost roll-coupled unit of the truck. It indicates how close that unit came to lifting off all of its tires on one side, and should not exceed 0.6.

Transient high-speed offtracking is the peak overshoot in lateral position of the last axle of the truck from the path of the front axle of the power unit, an indication of potential intrusion into an adjacent lane of traffic. It should not exceed 0.8 m.

The final three measures were obtained from a low-speed (8.8 km/h) 90 degree right-hand turn of 14 m radius at the power unit's left front wheel :

Low-speed offtracking is the inboard offtracking of the rearmost axle of the vehicle from the path of its front axle. It should not exceed 5.25 m, based on the turning performance of large tractor-semitrailers.

Outswing is intrusion into an adjacent lane by the truck's left rear corner, and should not exceed 0.2 m.

Friction demand represents the resistance of multiple axles to travel around a tight-radius turn, and describes the minimum friction needed at the power unit drive axles for the vehicle to make a turn without jackknife. It should not exceed 0.1.

The baseline cases, with nominal weights and dimensions, were run first for all configurations. The principal parameters affecting the stability and control of each configuration were identified, and parametric analyses were run to determine the range of each parameter that gave acceptable performance. Parameters ranged from M.o.U. limits to those of the least restrictive jurisdiction. Where a liftable axle was used on a baseline vehicle, it was replaced first with a typical automotive steer self-steering axle, then a typical turntable steer axle.

2.2/ Full Scale Test

A limited full-scale test was carried out to show that simulation could predict characteristic vehicle responses properly, and could predict trends in response as a function of vehicle dimensional changes. This was not validation of the computer simulation, it simply provided confidence that dynamic simulation was a reliable basis for decisions on regulatory principles. It parallels a process used during the Weights and Dimensions Study [8].

2.3/ Vehicle Naming Convention

The vehicle configuration code identifies axle units and hitches from the front to the rear of the vehicle. It implicitly identifies vehicle units, then the combination. It has codes for a liftable single axle (A); self-steering single axle (C); tandem axle (D); tridem axle (M); fixed single axle (I); single front steering axle (S); twin front steering axle (T); fifth wheel (1); pintle hitch (4); and double (C-dolly) hitch (5).

Consider the configuration code SAD411D. A hitch code (a number) terminates a vehicle unit. SAD4 is the power unit. It has a single front steering axle, a liftable single axle, a tandem drive axle and a pintle hook, so is a 4-axle straight truck with a pintle hook. It tows I1, a vehicle unit with a single axle fitted with a fifth wheel, a single axle A-dolly. This tows D, a vehicle unit with a tandem axle, a semitrailer.

3/ STRAIGHT TRUCKS

3.1/ The Trucks

The six straight trucks are shown in Figure 1. The 2-axle truck was excluded as it is not known to have dynamic performance problems. The baseline case for each truck followed Ontario regulations, with front axles rated about 9000 kg, and a tandem drive axle load of 17900 kg, because the majority of these vehicles operate in Ontario. These trucks share the payload between the front and drive axles.

The 3-axle straight truck, configuration SD, has a wheelbase of 5.08 m (200 in) and a 4.88 m (16 ft) long box. It is widely used for both heavy loads and utility purposes, and is generally regarded as having satisfactory performance.

The four 4-axle straight trucks have a 5.79 m (19 ft) long box, but different axle arrangements. Configuration SM has a tridem drive axle that shares the load equally between axles, with a spread of 3.06 m (120 in). It is rare. Configuration SAD has a wheelbase of 6.02 m (237 in) and its second ("pusher") axle is a liftable axle. Because of its greater payload capacity, this configuration has largely supplanted the 3-axle truck in Ontario for many commodities, except excavated material and garbage, where access considerations limit dimensions. It is rare elsewhere. The fourth ("tag" or "booster") axle of configuration SDA is a liftable axle that is often a free-castering self-steering axle, 3 m (118 in) or more behind the last drive axle, where this large spacing is used to accrue a higher gross weight. It seems to be used mostly as a concrete truck. Configuration TD has a heavy duty twin steer front axle. It is also widely used as a concrete truck, and as a dump and a garbage truck in Quebec.

The 5-axle straight truck, configuration TM, has the same twin steer front axle as configuration TD, and the same tridem drive axle as configuration SM. It may be used more as a platform for mobile cranes and other specialized equipment than as a truck.

3.2/ Simulation of Baseline Vehicles

The critical performance measures for straight trucks, rollover, handling and friction demand, are summarized in Table 1. All other performance standards are easily met.

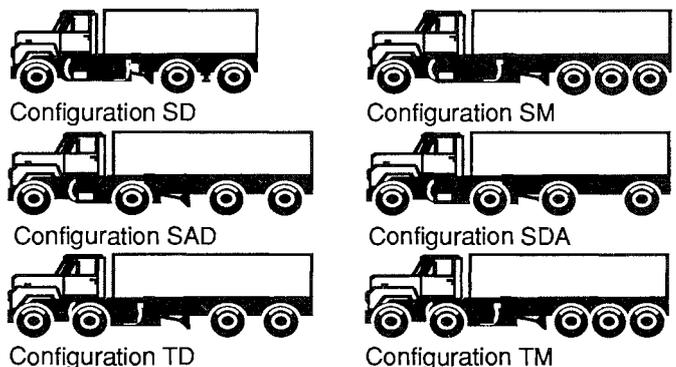


Figure 1/ Straight Trucks

Table 1/ Summary of Results

Truck	Performance Measure		
	Rollover	Understeer	Friction demand
SD	Much better	Acceptable	Much better
SM	Much better	Acceptable	Much worse
SAD	Close	Acceptable	Close
SDA	Much better	Much worse	Worse
TD	Much worse	Acceptable	Much better
TM	Much worse	Acceptable	Much worse

The twin steer configurations TD and TM clearly have poorer rollover characteristics than the other trucks. Their cargo box is located so that the load must be biased to the front to utilize fully the front axle load, which elevates the load centre of gravity. The roll stiffness of the second front axle is relatively low to provide a good ride for the driver. It does not compensate for the roll moment from the greater payload and its elevated centre of gravity when either of these trucks is compared to the 3-axle truck of configuration SD. These trucks are also usually fitted with non-load equalizing front suspensions. Without direct means to ensure that twin-steer trucks meet a rollover standard, are equipped with a load-sharing tandem front axle unit, and have proper load distribution, the twin-steer arrangement could not be recognized.

The tridem drive axle configurations SM and TM clearly have poorer friction demand characteristics than the other trucks. This would be resolved by making one of the three drive axles self-steering or forced steering. However, a self-steering axle would probably need single tires and so would have to be liftable. Forced steering technology is not widely available for this class of vehicle. Finally, ensuring a true load-sharing tridem axle may be difficult. Without a workable tridem drive axle that equalizes axle loads, and meets the friction demand criterion, the tridem drive arrangement could also not be recognized.

Configurations SAD and SDA also failed the friction demand standard, and configuration SDA clearly had the poorest handling characteristics.

The only configuration that met all performance standards was the 3-axle straight truck.

3.3/ Parametric Analysis

Allowable front axle load of the configuration SD determines in part the truck's payload weight. A lower front axle load decreases the payload and the overall centre of gravity height of the vehicle, so increases the rollover threshold.

The friction demand performance of configuration SAD can be improved if the fixed liftable axle is replaced by a self-steering axle. That axle must be properly located [10], which may not always achieve maximum allowable gross weight. Many trucks of this configuration cannot be loaded for proper axle load distribution, which results in inadequate front axle loads and dramatic drive axle overloads, even if the liftable axle is properly loaded. This configuration might be satisfactory if it would be designed with proper load distribution and control of the liftable axle load could be assured at a times. In the meantime, it also could not be recognized.

The friction demand performance of configuration SDA can be improved if the liftable tag axle is

replaced by a self-steering axle. Most such trucks are of this design, particularly concrete trucks, with an inter-axle spacing of 2.5 m or more. For such a truck, the large spacing results in the tag axle having a very strong effect on the handling of the truck, and the truck may become extremely oversteer if the load on the liftable axle is not properly adjusted [11]. Positive steps to constrain the use of such tag axles should be considered. Other closely coupled tag axles, within perhaps 1.5 m of the last drive axle, such as the tractor with a liftable tag axle and the inter-city bus with its variable load tag axle, may not be as critical, though are still not desirable.

3.4/ Dimensional Considerations

The largest truck wheelbase readily available is about 7 m (280 in). Manufacturing standards for body rear overhang are based on truck wheelbase, and the longest body commonly produced is about 8.5 m (28 ft) long. Many straight trucks in the construction, agricultural and delivery sectors have dimensions limited by accessibility requirements. Other trucks carry dense payloads so that the truck is only the minimum length that achieves maximum gross weight. Most trucks therefore are well within the current overall length of 12.5 m allowed by all jurisdictions. It appears that those trucks that do approach 12.5 m carry permanently mounted equipment, such as a crane or a lift, or have an overhanging load. There was therefore no reason to change the current length limit,

The wheelbase of a heavy-duty straight truck always exceeds the 3.0 m inter-axle spacing set in the M.o.U., and is not long enough for offtracking to be an issue. There was no reason to limit wheelbase.

A driver creates space to turn right by approaching the turn as far left as possible in the entry lane. The left rear corner swings out due to overhang of the body behind the axles, and if it encroaches into the lane to the left, it could become a hazard to vehicles travelling in that lane. This is why effective rear overhang for semitrailers was limited to 35% of wheelbase [4]. Analysis of straight truck turning showed that the outswing performance standard would be met with any likely body overhang, so no control of rear overhang was necessary. Some jurisdictions were concerned about security of load, and vehicle controllability due to a reduced front axle load, for a load with a large overhang, so rear overhang was limited to 4.0 m, including load.

4/ TRUCK-PONY TRAILERS

4.1/ Definitions

The pony trailer (also, pony pup, stiff-pole pup or truck pup) has a short body mounted more or less centrally over an axle unit that carries the load of both trailer and payload, with little load transfer to the towing truck, and a drawbar that is a rigid forward extension of the trailer frame. The pony trailer is generally a tandem axle trailer, but here it includes all trailers with a non-articulating drawbar. The pony trailer is towed by a straight truck with a pintle or ball hitch which has no resistance to rollover, or by a low-mounted stinger fifth wheel. A truck-pony trailer combination has one articulation point, at the truck hitch.

The pony trailer could fall within some definitions of semitrailer, as it has one axle unit and one point of articulation. However, it is not towed by a tractor, only by a straight truck, even if the truck has a stinger fifth wheel. Its axles are at the centre of its body, not the rear. It could also fall within the definition of a full

trailer, as both carry their load on their own axles. However it has one axle unit at its centre, whereas the full trailer has an axle unit at each end. A truck-pony trailer has one articulation point, whereas a truck-full trailer has two, one at the hitch and the other where the dolly attaches to the trailer body.

Consider the salient differences between the tractor-semitrailer and truck-pony trailer, and the effect these have on their relative stability. The tractor's fifth wheel has a forward hitch offset, whereas the truck's hitch has a large rearward offset, so the truck-pony trailer has slightly less offtracking but a significant increase in rearward amplification. The tractor's fifth wheel provides roll coupling, and the hitch used by most truck-pony trailers provides negligible roll coupling. The semitrailer has its axles at the rear, whereas the pony trailer has its axles in the middle of the trailer, so its shorter wheelbase decreases offtracking but increases rearward amplification significantly. The semitrailer is long and has a large yaw moment of inertia, so responds slowly to steer inputs, and the pony trailer is short and has a lower yaw inertia, so is more responsive to steer inputs. In all these respects, therefore, the truck-pony trailer combination is a less stable combination than the tractor-semitrailer, as summarized in Table 2 below.

The pony trailer is physically and dynamically different from the both the semitrailer and the full trailer, so the following definition was adopted :

Pony trailer means a vehicle that is designed to be towed by another vehicle, is equipped with a drawbar that is rigidly attached to the structure of the trailer, and is so designed and used that the preponderance of its weight and load is carried on its own axles.

This definition could include a wide range of utility, boat, house or other trailers that are towed by light duty vehicles, so it was limited to trailers with a manufacturers gross vehicle weight rating in excess of 10000 kg.

4.2/ The Trucks

The majority of truck-pony trailer combinations appear to be used in the construction sector for aggregates and bricks; in the agricultural sector for feeds, grains and milk; and in the industrial sector as a tanker. Few have a van body.

Three truck-pony trailer combinations drawn by the 3-axle straight truck of configuration SD are shown in Figure 2. Others were included in the original basic configurations, but are not reported here because their trucks failed to meet the performance standards as a single unit vehicle. Configuration SD4D has a pony trailer with a 4.88 m (16 ft) long box and a 1.83 m (72 in) spread tandem axle. Configuration SD4M has a pony trailer with a 5.79 m (19 ft) long box and a 3.05 m (120 in) spread tridem axle. Configuration SD4AD has a pony trailer with the



Configuration SD4D



Configuration SD4M



Configuration SD4AD

Figure 2/ Truck-pony Trailers

same box as configuration SD4M, but a fixed tandem axle towards the rear of the box and a liftable axle at the front.

4.3/ Simulation of Baseline Vehicles

Like the straight trucks, the payload centre of gravity for these vehicles is relatively low. In fact, in the high-speed turn, the truck rolled over before the pony trailer in all cases. No yaw instability was identified for any of these vehicles below their rollover threshold, though the pony trailer degraded the understeer coefficient of the straight truck by a small amount.

All trucks exceeded the load transfer ratio standard of 0.6. Configuration SD4M came close to rolling over its pony trailer. The pony trailer would roll over before the truck in all cases, due to its high rearward amplification. The transient high-speed offtracking is generally much higher than the criterion of 0.8 m, and would suggest the possibility of side-swipe type accidents from evasive manoeuvres. The short wheelbase of the pony trailer results in a manoeuvrable vehicle. However, it increases the friction demand of the truck. All trucks failed this performance standard, configuration SD4D by a small amount and the other two by a wide margin. They might be susceptible to jackknife while making a tight turn on a very slippery roadway.

4.3/ Parametric Analysis

The stability and control analysis found that load transfer ratio and friction demand are the principal performance measures of concern. They are strongly affected by hitch offset and pony trailer wheelbase, shown in Figure 3, and the number and spread of trailer axles.

For a fixed inter-vehicle unit distance, the hitch offset determines the wheelbase of the trailer. As the hitch offset is increased for a fixed inter-axle spacing, load transfer ratio, transient offtracking, and friction demand responses all increase. For a fixed hitch

Table 2/ Comparison of Stability properties of Tractor-semitrailer and Truck-pony trailer

Property	Tractor-semitrailer	Truck-pony trailer	Effect on Stability
Hitch location	Forward	Rearward	Worse
Hitch type	Fifth wheel	Pintle hook	Worse
Wheelbase	Long	Short	Worse
Inertia	High	Low	Worse

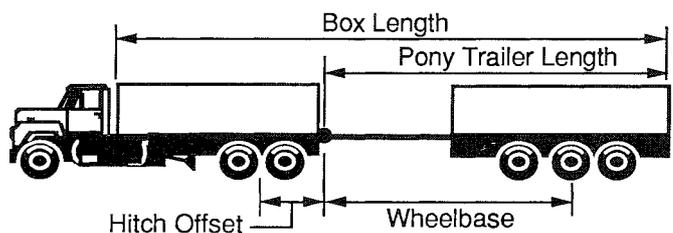


Figure 3/ Truck-pony Trailer Dimensions

offset, the load transfer ratio, transient offtracking, and friction demand all diminish as the trailer wheelbase is increased.

The performance standards for configuration SD4D for load transfer ratio and friction demand can both be met at a hitch offset of 1.5 m with a pony trailer wheelbase of 6.5 m, and at a hitch offset of 1.8 m with an 8.3 m wheelbase. Both these surpass the M.o.U.'s tandem-tandem inter-axle spacing of 5.0 m, and result in quite a long drawbar.

Hitch offset should be controlled to the absolute minimum possible value, to reduce the effect of rearward amplification. There appears no practical reason why the hitch offset should not be well within 1.5 m for a pintle hook or ball hitch, even with a 1.83 m (72 in) drive axle spread. A fifth wheel requires more clearance, and 1.8 m should be an equally practical upper limit in this case. As few straight trucks have a drive axle spread greater than 1.52 m (60 in), in many cases, hitch offset can be less than the limits provided. Problems evidently arise with vehicles with permanently mounted equipment like hydraulic landing legs, lifts, and so on, though few such vehicles may tow trailers. It is possible that careful design of new vehicles could ensure that hitch offset is minimized. Use of a lesser axle spread on the trailer than the 1.83 m used in this analysis will also tend to improve performance. This configuration needs a minimum wheelbase of 8.5 m to ensure the performance standard is met.

A fifth wheel hitch provides roll coupling between the truck and pony trailer and clearly improves the load transfer ratio. The pony trailer only needs a 6.5 m wheelbase to meet the performance standard. However, this is not a practical alternative in end dump applications, where the greased surface of the fifth wheel would quickly become contaminated.

The tridem pony trailer configuration SD4M could only meet both friction demand and load transfer ratio standards if its tridem axle is restricted to a spread between 2.4 and 2.5 m, and the tridem axle load is strictly limited to 21000 kg. Wider spreads, or higher loads, should not be permitted by local option where such equipment does not already exist.

4.4/ Dimensional Considerations

Outswing considerations limit the pony trailer to an effective rear overhang of 4 m. Since an 8.5 m wheelbase is already long, there is little incentive to use any greater wheelbase. An overall pony trailer length of 12.5 m was provided, from front of drawbar to rear of trailer.

A cube van truck-pony trailer is currently being marketed with a box length of about 18 m and an overall length of 19.8 m (65 ft). It would be possible to generate a box length of over 21 m, and a load bed length over 20 m, within an overall length of 23 m, rather more than allowed for the B- or C-train. Truck-pony trailers can generate gross weight that could make them a definite alternative to the tractor-semitrailer, yet their stability and control characteristics may be considered marginal at best. A box length equal to the semitrailer lengths of 14.65 or 16.2 m (48 or 53 ft) is too short based on the maximum trailer dimensions suggested above, and would severely restrict use of this combination. The configuration should be restricted to a box length less than the 20 m allowed to the B- or C-train. The A-train's box length of 18.5 m is close to that of the largest known current vehicle, so appears appropriate.

A box length limit of 18.5 m should result in an overall length not much more than 21 m, so the

current 23 m overall length in the M.o.U. should be adequate for the truck-pony trailer.

5/ TRUCK-FULL TRAILERS

5.1/ The Trucks

A full trailer consists of a converter dolly and a semitrailer, or a converter dolly-like unit permanently attached to a trailer with a turntable. A truck-full trailer combination has two articulation points, one at the truck hitch and one at the trailer articulation point. A full trailer lacks the roll resistance of a semitrailer, because it is towed by a pintle hitch rather than a fifth wheel. Where the full trailer is one integral unit, or a tandem axle dolly is used, the drawbar is usually hinged at the dolly frame to avoid load transfer between the two vehicle units. Where a single axle converter dolly is used, the drawbar must be a rigid part of the dolly frame so that the dolly will stand up when the trailer is detached from the truck.

Five truck-full trailer combinations were selected for study, as shown in Figure 4, all drawn by the 3-axle straight truck of configuration SD. Others were included in the original basic configurations, but their trucks failed to meet the performance standards as a single unit vehicle so are not reported here. Configuration SD4I1I has a 5.18 m (17 ft) long 2-axle full trailer. Configuration SD4I1D has a 7.31 m (24 ft) long tandem axle trailer with an axle spread of 1.83 m (72 in). Configuration SD4D1D has a tandem axle A-dolly and a 9.12 m (30 ft) long tandem axle trailer with a 1.83 m (72 in) axle spread. Configuration SD4D1AD has a tandem axle A-dolly and the same trailer as configuration SD4D1D, with an additional liftable axle between the tandems. This configuration appears primarily to be used for haul of refuse containers. Configuration SD5C1I uses the same truck and trailer as configuration SD4I1I, but replaces the A-dolly with a C-dolly having the same drawbar length. The double drawbar configuration of the C-dolly provides roll coupling between the truck and trailer that is not available from the conventional A-dolly used in the other four trucks.

5.2/ Simulation of Baseline Vehicles

These trailers are longer per ton of payload than the pony trailers discussed above, so their payload

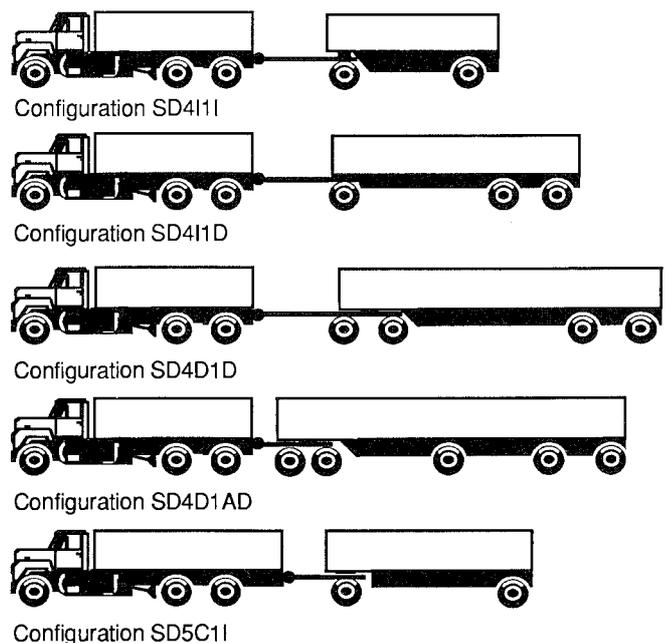


Figure 4/ Truck-full Trailers

centre of gravity is lower. Rollover in a steady turn does not appear to be a major concern.

Configuration SD5C1I has serious handling problems, because the C-dolly drawbar effectively provides the truck with a self-steering tag axle set far back from the drive axles. The high on-centre stiffness of the C-dolly demands a high steer angle, and when the path curvature generates a high enough side force for the axle to steer, the driver must compensate by reducing the front axle steer. At this instant, the vehicle suddenly becomes strongly oversteer. Depending on load and the state of axle maintenance, the handling of the vehicle can vary continuously as it is driven along the road. This serious handling deficiency has already led to a suggestion that this configuration should be prohibited [12]. It was agreed that C-dolly, or any other non-articulating dolly, should be prohibited from use in the truck-full trailer combination.

All truck-full trailer combinations except configuration SD5C1I failed the load transfer ratio and transient offtracking standards. They all met the friction demand standard, except for configuration SD5C1I, which failed by a wide margin.

5.3/ Parametric Analysis

Most truck-full trailers appear to carry relatively dense freight, which results in a moderate centre of gravity height, so rollover performance does not seem critical for typical current uses of this combination. The stability and control analysis found that load transfer ratio in a high-speed evasive manoeuvre is the primary performance measure of concern. This is strongly affected by hitch offset, drawbar length and trailer wheelbase, shown in Figure 5.

The hitch offset considerations are the same as for pintle hitch for the truck-pony trailer combination. The smaller the hitch offset, the lower the load transfer ratio and transient offtracking. This should be controlled to the absolute minimum possible value, to reduce these effects of rearward amplification.

Increased drawbar length and increased trailer wheelbase both also reduce the effect of rearward amplification, but are not as strong parameters in this regard as hitch offset. The performance of the truck-pony trailer and truck-full trailer can be improved if sufficiently large dimensions can be prescribed.

Configuration SD4I1I, with a 2-axle full trailer, was not particularly sensitive to drawbar length. With a hitch offset of 1.5 m, it met the load transfer ratio performance standard at a wheelbase around 6.5 m, which results in a trailer considerably longer than the typical 4.5-5 m (15-16 ft) length of such trailers.

Configuration SD4I1I, with a 3-axle full trailer, was also not sensitive to drawbar length. With a hitch offset of 1.5 m, it met the load transfer ratio performance standard at a wheelbase around 8 m, which also results in a trailer considerably longer than the typical 6.5-8 m (21-26 ft) for such trailers.

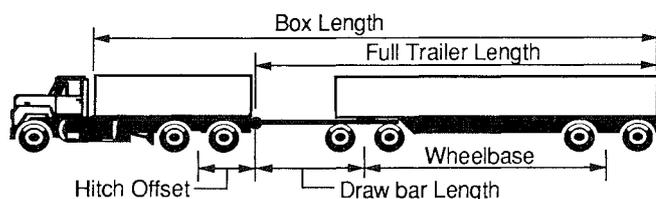


Figure 5/ Truck-full Trailer Dimensions

Configuration SD4D1D, with a 4-axle full trailer, was moderately sensitive to drawbar length, and its stability improved as drawbar length is increased. With a hitch offset of 1.5 m, and a drawbar length that meets the minimum tandem-tandem inter-axle spacing of 5 m, it met the load transfer ratio performance standard with a wheelbase of about 7.5 m.

Drawbar length does not seem to affect load transfer ratio strongly, so inter-axle spacing can be allowed to control drawbar length. This is a simplification, as it avoids conflict between hitch offset, drawbar length and inter-axle spacing where different trucks may tow different trailers.

By limiting the truck-full gross weight to that of the tractor-semitrailer or A-train with the same number of axles, a minimum wheelbase of 6.5 m was possible for all full trailers.

5.4/ Dimensional Considerations

The length of a full trailer was defined as : **Length (full trailer)** means the longitudinal dimension from the front of the cargo carrying section of the full trailer to its rear, exclusive of any extension in length caused by auxiliary equipment or machinery at the front that is not designed for the transportation of goods.

Some truck-trailers can generate gross weight or volume that could make them an alternative to a tractor-semitrailer or B- or C-train if given any advantage over these in box length, gross weight or axle capacity. The stability and control characteristics of typical truck-full trailers are marginal at best. If the configuration is to be endorsed, it should be subject to the same 18.5 m box length limit as the A-train, and allowed a gross weight no greater than the tractor-semitrailer or A-train with the same number of axles.

A box length limit of 18.5 m should result in an overall length not much more than 21 m, so the current 23 m overall length in the M.o.U. should be adequate for the truck-full trailer.

6/ TRACTOR-SEMITRAILER-PONY TRAILERS

6.1/ The Trucks

The tractor-semitrailer-pony trailer combination is a double trailer combination that has two points of articulation, at the tractor fifth wheel and the semitrailer hitch, like a B-train. However, this combination compares unfavourably with a B-train for the same reason a truck-pony trailer compares unfavourably with a tractor-semitrailer, as shown in Table 2. It appears to be used primarily in aggregate and grain dump applications.

Three configurations were selected, as shown in Figure 6, all using the same 3-axle tractor.

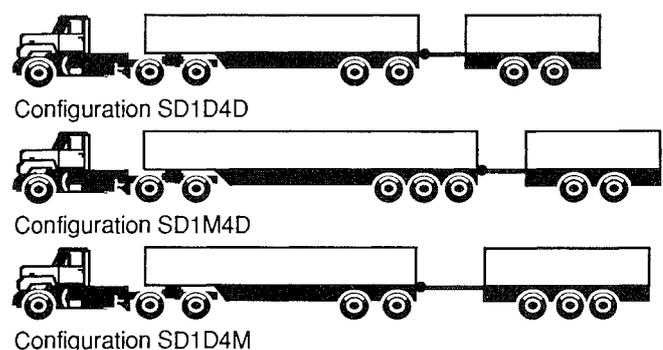


Figure 6/ Tractor-semitrailer - Pony Trailers

Configuration SD1D4D has an 8.53 m (28 ft) long tandem axle semitrailer and is fitted with a pintle hook to tow the same tandem axle pony trailer used in configuration SD4D. Configuration SD1D4M has the same semitrailer as configuration SD1D4D, but with the 5.79 m (19 ft) tridem axle pony trailer used in configuration SD4M. Configuration SD1M4D has the same pony trailer as configuration SD1D4D, but has a 10.06 m (33 ft) tridem axle semitrailer.

6.2/ Simulation of Baseline Vehicles

All three tractor-semi-trailer-pony trailers met all performance standards except for load transfer ratio and transient offtracking.

6.3/ Parametric Analysis

The use of a fifth wheel hitch for the pony trailer substantially tames the rearward amplification. It provides rollover resistance for the pony trailer, and the load transfer ratio is much reduced. It comes close to meeting transient offtracking performance standard. Indeed, it would be possible to allow it without a wheelbase limitation, simply let the inter-axle spacing ensure there was an adequate wheelbase. However, this configuration may not be practical in end-dump applications, as the fifth wheel may get contaminated when the semitrailer is dumped.

In contrast, with a pintle hook, the pony trailer needs the full 8.5 m wheelbase even to come close to the performance standards for load transfer ratio and transient offtracking.

Hitch offset has a very strong effect on the rearward amplification response of all combination vehicles. It should be controlled to the minimum possible value, to reduce the effect of rearward amplification. Increased semitrailer wheelbase also reduces the effect of rearward amplification.

6.4/ Dimensional Considerations

The tractor-semi-trailer-pony trailer can generate gross weight or volume that could make it an alternative to the B- or C-train if it is given any advantage over these in box length, gross weight or axle capacity. The stability and control characteristics of typical tractor-semi-trailer-pony trailer combinations are marginal at best. The configuration should be subject to the same 18.5 m box length limit and 53500 kg gross weight limit as the A-train.

A box length limit of 18.5 m should result in an overall length not much more than 21 m, so the current 23 m overall length in the M.o.U. should be adequate for the tractor-semi-trailer-pony trailer.

7/ SUMMARY OF REGULATORY PRINCIPLES

7.1/ M.o.U. Standards

The following regulatory principles are all expressed within the context of the M.o.U., which defines single, tandem and tridem axle units and their allowable loads, spreads and spacings. It also states that none of the axles may be liftable or self-steering. By specifying overall and internal dimensional constraints, it ensures defined configurations meet the performance standards.

7.2/ Straight Trucks

The straight truck shall be limited to a single front steering axle and either a single or tandem drive axle.

The maximum front axle load should not exceed 7-8000 kg, to ensure proper load distribution.

The maximum overall length for a straight truck shall not exceed 12.5 m

There need be no limit on straight truck wheelbase.

The rear overhang, from the truck's turn centre to its rear, including load, shall not exceed 4 m.

While the M.o.U. states that no province need allow liftable or self-steering axles, trucks with self-steering and/or liftable axles do exist. There may be major stability and control deficiencies with these trucks, particularly as the spacing of a tag axle behind the drive axles increases, and consideration should be given to constraints on use of such tag axles.

7.3/ Truck-pony Trailer

Truck hitch offset shall be the minimum possible, but not more than 1.8 m for a fifth wheel, nor 1.5 m for any other hitch.

The pony trailer shall be fitted with a tandem axle, or a tridem axle with a spread between 2.4 and 2.5 m.

The wheelbase of a pony trailer shall not be less than 6.5 m when towed by a fifth wheel, or 8.5 m with any other hitch.

The length of a pony trailer shall not exceed 12.5 m, from front of drawbar to rear.

The box length of a truck-pony trailer combination shall not exceed 18.5 m.

The truck-pony trailer combination should be limited to the gross weight of the tractor-semi-trailer with the same number of axles.

7.4/ Truck-full Trailer

A C-dolly or other non-articulating dolly shall not be used in a truck-full trailer combination.

Truck hitch offset shall be the minimum possible, but not more than 1.5 m.

The full trailer shall be allowed only a single axle dolly and single axle or tandem axle trailer, or a tandem axle dolly and tandem axle trailer

The length of a full trailer shall not exceed 12.5 m, from front of drawbar to rear.

Drawbar length need not be controlled.

The minimum full trailer wheelbase is 6.5 m.

The box length of a truck-full trailer combination shall not exceed 18.5 m.

The truck-full trailer combination should be limited to the gross weight of the tractor-semi-trailer or A-train with the same number of axles.

7.5/ Tractor-semi-trailer-pony Trailers

The tractor-semi-trailer-pony trailer combination should be combined in an "other" category to encompass all double trailer combinations that are not B- or C-trains.

8/ TEST PROGRAM

The power unit was a typical 3-axle dump truck that was used to tow a tandem axle pony trailer, configuration SD4D, and also a 3-axle full trailer, configuration SD411D. The test program investigated vehicle responses to a sinusoidal steer input with a period between about 1.5 and 4.5 seconds. The hitch offset was varied for both trailers, and the drawbar length and wheelbase were varied for the full trailer. Test results were processed to yield time histories of vehicle responses and rearward amplification of lateral acceleration, for comparison with simulations conducted using the measured steer input, and estimates of properties of the vehicle units [13].

Figure 7 shows typical vehicle responses, and Figure 8 shows a typical envelope of rearward amplification of lateral acceleration, in comparison with the simulation results. The test generally confirmed the trends in vehicle response due to changes in dimensional parameters, and showed that the simulation could adequately represent these classes of vehicle.

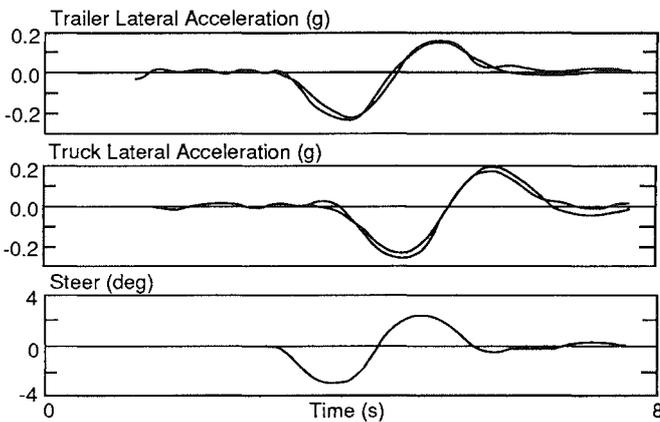


Figure 7/ Comparison Between Test and Simulation
Truck-Pony Trailer, Short Hitch Offset,
60 km/h

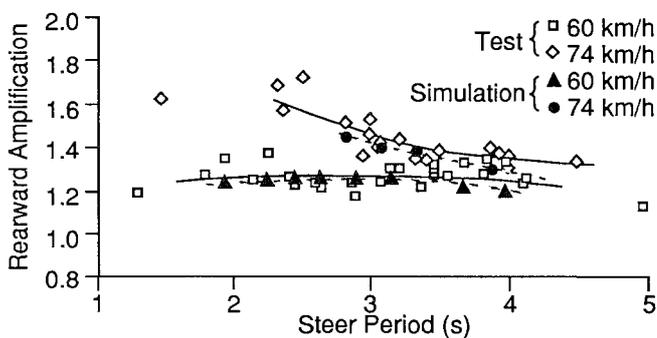


Figure 8/ Truck-pony Trailer Stability Analysis,
Nominal and 4-foot Hitch Offset

9/ CONCLUSIONS

The stability and control characteristics of straight trucks and truck-trailer combinations have been evaluated against performance standards similar to those developed in the Vehicle Weights and Dimensions Study.

Vehicle rollover is not an issue for these configurations because of the relatively low centre of gravity in typical high gross weight applications, except for straight trucks having twin steer. Twin steer front axles should be discouraged on straight trucks, especially for high centre of gravity payloads.

Any truck with more than two axles, other than the front steering axle, or any truck-pony trailer where the pony trailer has more than two axles, does not meet the friction demand criterion. Tridem drive axles should be discouraged, and pusher axles that are liftable and not self-steering should be discouraged. This configuration should only be considered if tight controls for liftable and self-steering axles can be developed and proven, and if proper loadability can be assured.

Use of a tag axle severely degrades the yaw stability of the straight truck, especially when that axle is either liftable or self-steering. A straight truck should be prohibited from using a variable load or a self-steering tag axle, at least if that axle is widely separated from the last drive axle.

Use of a C-dolly, or other double drawbar dolly, in a truck-trailer combination severely degrades the yaw stability of the straight truck. A straight truck should be prohibited from towing a full trailer that uses a C-dolly or other double drawbar dolly.

The truck-pony trailer, truck-full trailer and tractor-semitrailer-pony trailer all have high responses to a high-speed evasive manoeuvre. This is sensitive to hitch offset, drawbar length and trailer wheelbase. In general, the longer the dolly drawbar or trailer wheelbase, or the shorter the hitch offset from the centre of the truck's drive axle unit, the lower the response. The hitch offset on the truck should be the minimum practical. Current minimum values of inter-axle spacing provide adequate drawbar length. A similar gross weight constraint should be applied to these vehicles as is applied to the A-train double trailer combination.

A brief test program demonstrated corresponding changes in response due to hitch offset, drawbar length and wheelbase as the computer simulation.

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