AN ASSESSMENT OF TANK TRUCK ROLL STABILITY

J.R. Billing and J.D. Patten

National Research Council of Canada

John R. Billing

Senior Research Officer
Centre for Surface Transportation Technology, National Research Council of Canada
31 La Peer Blvd, Agincourt, Ontario, Canada
(416)-499-3202
jrbilling@sympatico.ca

ABSTRACT

Transport Canada's Dangerous Goods Directorate (TDG) data base of crashes involving a vehicle carrying dangerous goods shows 810 rollovers in 1,874 reported crashes from 1990 to 1998, and 83% of these involved highway tank trucks. TDG is therefore considering approaches to improve the rollover stability of tank trucks used for highway transportation of dangerous goods.

TDG asked the Centre for Surface Transportation Technology of National Research Council Canada (NRC/CSTT) to conduct tilt tests to determine the rollover threshold and rollover characteristics of tank truck configurations. 17 vehicles were tested, which included the principal configurations of tank truck in service across Canada, and between Canada and the U.S. A computer simulation was shown to be able to match the rollover characteristics and roll threshold of each vehicle tested, including those where the liftable axles of vehicles so equipped were raised. The simulation was used to project the lowest roll threshold of each vehicle, with tanks full and loaded to its allowable gross weight.

National regulatory authorities have adopted 0.40 g as the minimum roll threshold for tank trucks. 7 of 17 (41%) distinct vehicles tested here would have a roll threshold under 0.35 g when loaded to their allowable gross weight in Ontario, while 14 of 17 (83%) would have a roll threshold under 0.40 g. The roll threshold of a vehicle with liftable axles drops by 0.01-0.03 g when those axles are raised to turn.

This paper presents the background and results of this study, with some discussion of vehicle design and configuration issues.

AN ASSESSMENT OF TANK TRUCK ROLL STABILITY

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1 INTRODUCTION

Transport Canada's Transport Dangerous Goods Directorate (TDG) maintains a database of reportable incidents for vehicles carrying dangerous goods. 810 (43%) of 1,874 incidents from 1990 to 1998 resulted in rollover, and 671 (83%) of the 810 vehicles that rolled over were tank trucks (Woodrooffe, 2000). Transport Canada's accident database shows that less than 5% of all heavy truck crashes involve rollover of the truck (Billing, 2004). TDG was justifiably concerned about the high proportion of rollovers in tank truck crashes, and is considering approaches to improve the rollover stability of tank trucks approved for highway transportation of dangerous goods. TDG requested the Centre for Transportation Technology of the National Research Council of Canada (NRC/CSTT) to conduct a comprehensive series of tilt tests to characterize the rollover threshold of tank trucks that operate in Canada (Billing and Patten, 2005).

2 TILT TEST EQUIPMENT AND PROCEDURES

These tests used the NRC/CSTT tilt table shown in Figure 1 (Delisle and Pearson, 1986). The tilt table has two sections, each 12.19 m (40 ft) long and 3.05 m (10 ft) wide, hinged on the low side, and raised by two hydraulic actuators on the high side. The two sections are controlled to rise together. The tilt table can handle any legal vehicle that operates in Canada.

The tilt table has eight load pads, each about 3.35 m (133 in) long, that provide the normal force applied by all wheels in contact with the load pad. The load pads were positioned on the tilt table to match the axle locations of the vehicle, and the space between them was filled with timbers so the vehicle can drive across the tilt table. Individual wheel scales were used to measure additional wheel weights on the high side on a vehicle with more than four axle groups. Tilt angles were measured using tilt sensors attached to the deck of the table, the front bumper of a power unit, a frame rail of a tractor or B-train lead semitrailer close to its fifth wheel, the upper coupler plate of a semitrailer, and the rear bumper of a semitrailer.

Standard NRC/CSTT procedures were followed to gather information about each vehicle and its load, to prepare vehicles, to conduct the tests following Society of Automotive Engineers Standard J2180, and to return the vehicle to its owners. At least three tilt tests were conducted for each vehicle in each direction. When a vehicle with an air suspension is subject to a tilt test, roll of the vehicle can lead to un-representative activation of the height control valve, and lateral air transfer. Shut-off valves were installed that prevented filling or venting of air due to operation of each height control valve, and side-to-side air transfer between suspensions. These valves were removed after the final tilt test.

Figure 1: Tilt Table

Equivalent lateral acceleration was computed as the tangent of the tilt table angle. Wheel loads and tilt angles were plotted against time and equivalent lateral acceleration, up to the highest tilt angle achieved by the tilt table. The load transfer ratio LTR is a measure of vehicle rollover performance that is computed continuously from low- and high-side wheel loads as $LTR = (\sum L - \sum H)/\sum(L+H)$, where L are the instantaneous low-side wheel loads during a tilt test, H are the corresponding instantaneous high-side wheel loads, and $\sum$ indicates summation over axles. The summation excludes the front axle, because the front suspension is so soft that the front axle usually stays firmly on the tilt table even though a vehicle has become unstable in roll and is hanging on its tiedowns. The load transfer ratio is initially zero, when the tilt table is level, as $\sum L = \sum H$, and rises to 1.0 when all high-side wheels have lifted, as $\sum H = 0$. The load transfer ratio was plotted against equivalent lateral acceleration. All these plots provided valuable insights into the rollover characteristics of a vehicle, including lift-off of each wheel, fifth wheel separation and the lash transition of a leaf spring suspension.

3 COMPUTER SIMULATION PROCEDURES

Computer simulations were conducted for all vehicles tested using a new model developed for this work that uses Microsoft Excel for data entry and collection of results, with a companion program to run the simulation. The model combines the solution procedure of the original Static Roll Model (Dill, 1985), extended to allow a B-train double and liftable axles on each vehicle unit, with a generalized model for the cross-section of a tank and for fluid flow within that tank (Southcombe, Ruhl and Kuznetsov, 2000).

Data necessary for simulations were gathered during the test. An initial simulation run was made using nominal suspension data, and the results were compared to measured load pad forces and tilt and roll angles. The results were generally fairly close. However, the actual suspension operating conditions were often somewhat different than those for the data used, so the data for each suspension were adjusted iteratively to improve the match between simulation and test results for each test. It was always possible to achieve a reasonable match for component values within a reasonable range for each of the suspension parameters adjusted. An additional simulation was conducted using the same methodology for one tilt test with liftable axles raised, when a vehicle was so equipped, so simulation results matched the test results as well as possible with liftable axles down, and with them raised, using the same modified suspension data.

The simulation was able to match the rollover process sufficiently closely that the threshold predicted was generally within 0.005 g of the value determined from the tilt test. Collectively, the simulation results show that the Static Roll Model, as adapted and extended for this work, and using appropriate data, is reasonably able to represent the responses measured from the vehicles during the tests.

4 TILT TEST RESULTS AND DISCUSSION

4.1 Standards for Roll Threshold

A number of standards have been established or proposed for the roll threshold of heavy vehicles. New Zealand has a minimum roll threshold of 0.35 g for all vehicles (Land Transport Safety Authority, 2003), and Australia has proposed the same under its performance-based standards, except for tank trucks and buses (National Road Transport Commission, 2002). The United Nations Economic Commission for Europe (UNECE) has a minimum roll threshold of 0.40 g for tank trucks by tilt test, or 0.42 g by calculation (UNECE, 2000). Australia has proposed 0.40 g for tank trucks and buses under its performance-based standards. Canadian provinces have often used 0.40 g for vehicles that operate by special permit (Roads and Transportation Association of Canada, 1986). There seems some consensus that 0.35 g should be the lower limit for the roll threshold for all vehicles, with 0.40 g for tank trucks.

4.2 Results

Table 1 presents the tilt test results in order of increasing average roll threshold from all tilt tests conducted with any liftable axles on a vehicle down. There are three straight trucks; four five-axle tractor-semitrailers; six six-axle tractor-semitrailers, one with a tridem and five with a tri-axle; one seven-axle tractor-semitrailer; one eight-axle tractor-semitrailer; and three eight-axle B-trains. Each vehicle is a typical highway tank truck that may be used across Canada, in the six eastern provinces, or in Ontario, depending on its configuration. Each tank truck was loaded with a typical amount of the product it usually delivers, except for Vehicle 10, which was loaded with water. Vehicle 06 was the same physical vehicle as Vehicle 05, with a lesser amount of payload. It was difficult to get vehicles of any particular axle configuration and tank specification for a tilt test, and those vehicles that were tested were those graciously made available by their owners for that purpose. Some configurations were simply not available. For example, the straight bore tandem semitrailer is about 25% of all tank trucks, but only one was tested, and that had to be filled with water.

The rows with a grey background at the top of Table 1 identify vehicles with an average roll threshold below 0.35 g. The rows with a white background identify vehicles with an average roll threshold between 0.35 and 0.40 g. The rows with a grey background at the bottom of the table identify vehicles with an average roll threshold over 0.40 g. Table 1 simply stratifies the results according to the consensus values for roll threshold performance, discussed above.

Table 1: Stratification of Tilt Test Results

No	Vehicle Configuration	Spec	Year Built	Axles/ Liftable	Cargo	GVW (kg)	Avg RT (g)
16	B-train	331	1996	8/0	Liquid propane	62,259	0.310
18	Tractor-semitrailer	307	1974	6/1	Al_2SO_4	47,976	0.320
12	Tractor-semitrailer	331	1987	8/2	Liquid propane	59,181	0.333
05	Tractor-semitrailer	331	1991	6/1	Liquid CO_2	50,970	0.337
03	B-train	306	1995	8/0	Gasoline	63,011	0.343
04	Tractor-semitrailer	331	1982	5/0	Liquid CO_2	37,695	0.346
17	Tractor-semitrailer	341	1991	6/1	Liquid nitrogen	50,358	0.357
06	Tractor-semitrailer	331	1991	6/1	Liquid CO_2		0.359
13	Tractor-semitrailer	341	1996	5/0	Liquid nitrogen	37,967	0.365
08	Straight truck	306	1995	2/0	Heating oil	16,366	0.365
15	Tractor-semitrailer	341	1983	6/1	Liquid oxygen	52,038	0.367
07	Tractor-semitrailer	331	2001	6/0	Liquid CO_2	48,957	0.371
09	Straight truck	406	2001	3/0	Heating oil	25,637	0.383
11	Tractor-semitrailer	341	1978	5/0	Liquid oxygen	39,414	0.385
10	Tractor-semitrailer	None	2001	5/0	Water	33,006	0.408
01	Tractor-semitrailer	406	2002	7/3	Diesel fuel	61,803	0.415
14	Straight truck	331	2001	3/0	Liquid propane	17,857	0.469
02	B-train	306	1995	8/0	Diesel fuel	61,209	0.605

The results in Table 1 apply only to the exact vehicles tested. The results do not necessarily apply to any other vehicle of a particular configuration, tank specification or payload, which could conceivably fall into any of the three bands shown in Table 1 depending on details of its design. The lowest roll threshold for any particular vehicle is always a little lower than the average value shown, and the average roll threshold in tilt tests to the left and right differed by up to 0.033 g, with an average difference of 0.013 g. Table 1 shows that 6 of 17 vehicles, or 35%, had an average roll threshold below 0.35 g, and 13 of 17, or 76%, had an average roll threshold below 0.40 g. These proportions ignore Vehicle 06, which was physically the same vehicle as Vehicle 05, but with a lesser payload. The modest rollover thresholds for most of the vehicles tested are attributable to the high gross weights allowed in Canada, and also to design features of many current vehicles that appear to elevate their payload centre of gravity.

4.3 Effect of Gross Weight

The rollover thresholds presented in Table 1 are the average values for each vehicle as it was tested. These results cannot be taken completely at face value, because the gross weight ranged from 76 to 106% of the allowable value in Ontario. A computer simulation was conducted with each compartment filled in the most sensible manner to bring the vehicle to its allowable gross weight. This changed the roll threshold of most vehicles by a small amount without changing the band in which it fell in Table 1. Vehicle 17 and Vehicle 10 were both significantly under-loaded, and their roll thresholds fell well below 0.35 g and 0.40 g respectively, so each dropped one band. Consequently, if each vehicle had each been tested while loaded to its allowable gross weight, it is likely that 7 of 17 vehicles, or 41%, would have a roll threshold below 0.35 g, and 14 of 17, or 82%, would have a roll threshold below 0.40 g, again ignoring Vehicle 06.

4.4 Effect of Liftable Axles

Table 2 presents the average roll threshold results for those vehicles equipped with liftable axles, with the liftable axles both down and up. The table shows that the roll threshold is generally reduced by about 0.01-0.03 g when its liftable axle is raised, regardless of the centre of gravity height. The liftable axle must be raised to allow these configurations, which have widely spaced axles, to turn. The lateral acceleration that causes a rollover only arises when a vehicle turns. The normal use of rigid liftable axles thus increases the risk of rollover, except for the tightest right-hand turn at an intersection, where speed must be severely limited and the lateral acceleration is usually well below 0.15 g. This is not an issue if a liftable axle is also self-steering and does not need to be raised for the vehicle to turn.

Table 2: Effect of Liftable Axles on Roll Threshold

No	Vehicle Configuration	Spec	Year Built	No of Axles	Cargo	Avg RT (g) Lift Down	Avg RT (g) Lift Up
05	Tractor-semitrailer	331	1991	6/1	Liquid CO_2	0.337	0.312
06	Tractor-semitrailer	331	1991	6/1	Liquid CO_2	0.359	0.340
12	Tractor-semitrailer	331	1987	8/2	Liquid propane	0.333	0.333
15	Tractor-semitrailer	341	1983	6/1	Liquid oxygen	0.367	0.355
17	Tractor-semitrailer	341	1991	6/1	Liquid nitrogen	0.357	0.324
18	Tractor-semitrailer	307	1974	6/1	Al_2SO_4	0.320	0.313

The liftable axles typically had a ground clearance of about 0.08 m (3 in) when raised, and the low-side wheels invariably touched down in the latter stages of a tilt test, between the time the semitrailer high-side wheels lifted off and the time the drive axles lifted off. This provided an additional resistance to rollover, and acted somewhat like the outrigger used in a dynamic test because the suspension airbags were deflated and the raised axle was held against stiff bump stops, though the track width was insufficient to make a significant change in the roll threshold. The load on the raised liftable axle was not included in the calculation of load transfer ratio, and was ignored, to the extent possible, in the estimation of roll threshold. The rollover threshold of Vehicle 12 with its liftable axles up is certainly a slight over-estimate.

Rigid liftable axles have been widely used for over thirty years to allow vehicles to haul heavy payloads in the six easternmost provinces of Canada. These provinces have recognized that this has elevated the risk of bridge failure, and caused excessive wear on pavements. The provinces have therefore restricted the allowable gross weight on any new vehicle with a rigid liftable axle to such an extent that it will no longer be cost-effective, have reduced the allowable gross weight of some existing configurations with rigid liftable axles, and have scheduled further reductions. However, Ontario has exempted any tri-axle semitrailer built to the 331 specification in carbon dioxide service, or any tri-axle semitrailer built to the 341 specification, from any weight reduction until 2021. Vehicles can still be built in Québec and Ontario with liftable axles, but each liftable axle must carry the same load as each fixed axle, must be self-steering so that it does not need to be lifted for the vehicle to turn, and any lift control must not be accessible to a driver from the cab. A consequence of these changes is that carriers are likely to replace tri-axle semitrailers with new tridem semitrailers in the Atlantic provinces, and tridem or self-steer quad semitrailers in Québec. An example of the outcome could be that a tri-axle semitrailer like Vehicle 05 might be replaced by a tridem semitrailer like Vehicle 07, which changes the roll threshold from 0.337 to 0.371 g, from Table 1.

4.5 Vehicle Design Factors

Vehicle 01, shown in Figure 2, was a tractor-semitrailer with a drome tank on the tractor that can only operate in Ontario. The semitrailer tank was evidently designed to have a low centre of gravity in a way that some of the other vehicles were not, which resulted in a roll threshold over 0.40 g. This may have been helped by the use of wide single tires, which allow the tank to sit a little lower, and allowed the suspension spring spread to increase. However, the semitrailer tire track width was only 2.44 m (96 in). Increasing the track width to 2.54 m (100 in) might improve the roll threshold by about 7%, or about 0.03 g (Delisle and Pearson, 1986).

Vehicle 02, shown in Figure 3, was an 8-axle B-train configured to carry diesel fuel to northern Ontario and wood products on decks above the tanks on the return trip. The vehicle had a roll threshold over 0.60 g as a tanker, but its roll threshold would be much lower when carrying wood products, when it remains subject to the dangerous goods regulations because the tanks still contain volatile fumes. While the tanks on this vehicle were very low, this configuration is only practical for its specialized mission.

Figure 2: Vehicle 01, 7-axle Tractor-semitrailer with Drome Tank on Tractor

Figure 3: Vehicle 02, 8-axle Low-profile B-train

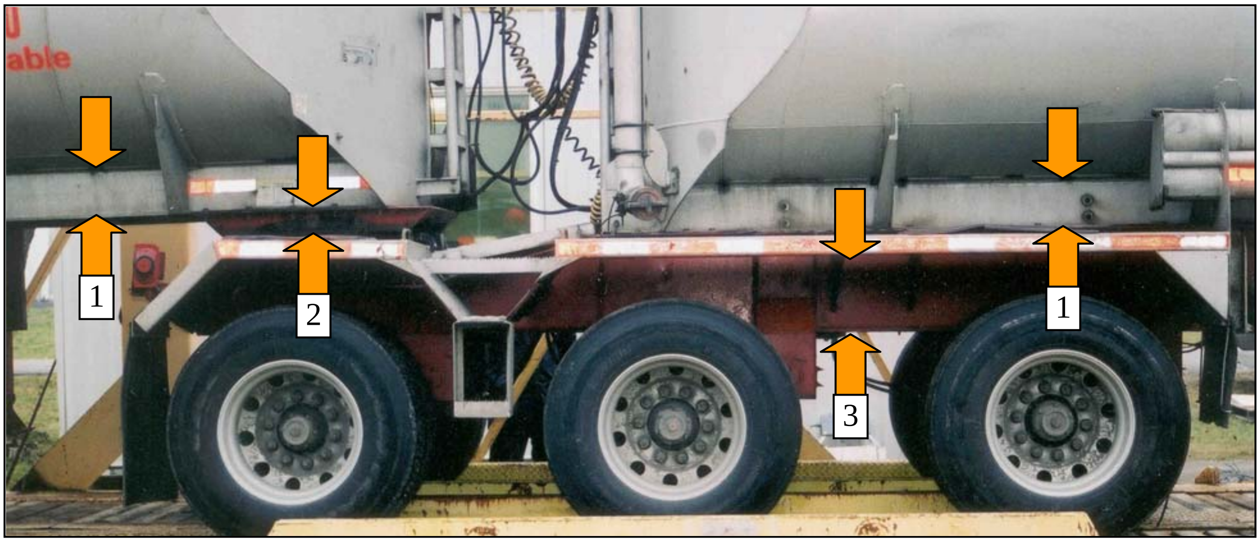

Figure 4: Design Features of 8-axle B-train Fuel Tanker

Figure 5: Tank Cross-sections

Figure 6: Canadian B-train Tankers (Left) and Australian B-train Tankers (Right)

Figure 4 shows the centre of a B-train fuel tanker. Label 1 shows the frame rails of each trailer, which are about 0.30 m (12 in) high, label 2 shows an upper coupler plate about 0.25 m (10 in) high, and label 3 shows a suspension sub-frame about 0.46 m (18 in) high. Figure 5 compares a rear view of Vehicle 01, with a relatively low tank centre, with a rear view of Vehicle 03 and Vehicle 12. The design features seen in Figure 4 were found in many of the tank trucks tested, and evidently contribute to the height of Vehicle 03 and Vehicle 12 seen in Figure 5.

Figure 6 compares Canadian and Australian B-train fuel tankers, in the top row on the left and right respectively, and B-train propane tankers, in the bottom row. The Canadian vehicles have eight axles and an allowable gross weight of 63,500 kg (140,000 lb), while the Australian vehicles have nine axles and an allowable gross weight that may be 62,500 kg (137,787 lb) for general use or 68,000 kg (149,912 lb) for a route-specific special permit. Each fuel tanker has about the same box length, though a different distribution of trailer lengths. If the top of the tractor side window is compared to the top of the tank, it is clear that the Australian vehicle is considerably lower than the Canadian vehicle. The propane tankers are also of comparable capacity, but the tanks of the Australian vehicle slope severely down to the rear, which clearly reduces the height of its centre of gravity. It is evident from these pictures that the Australian vehicles have a significantly lower centre of gravity than the Canadian vehicles, so a high roll threshold is clearly a priority for Australian manufacturers of tank trucks. In contrast, Canadian manufacturers appear to have standardized designs to reduce the cost of production. Canadian manufacturers are certainly aware that rollover is an issue, and try and avoid design changes that degrade the roll threshold, but considerations of capital cost and operational needs tend to take priority. These approaches probably reflect differing operating environments and priorities in the two countries. Australia requires that the stability angle of a tank truck, which is the angle between the horizontal and a line joining the payload centre of gravity to the outside edge of the tires at the ground, should not exceed 62 deg (Standards Australia, 1999). This is equivalent to a centre of gravity up to 2.39 m (94 in) for a trailer with a track width of 2.54 m (100 in). Some vehicles tested had a stability angle less than 62 deg and a roll threshold less than 0.35 g. Other vehicles had a stability angle greater than 62 deg and a roll threshold greater than 0.35 g. The stability angle is a simple concept, but it appears to provide both false positives and false negatives for current Canadian tank truck designs.

4.6 Approaches to Increase the Roll Threshold of Tank Vehicles

Tank truck rollovers should be reduced by increasing the roll thresholds of the tank truck fleet (Winkler et al, 2000). This is simply done by setting a requirement that any new tank truck should have a roll threshold not less than a specified value when loaded in its most critical condition. It is clear that the payload centre of gravity height of semitrailers and B-trains in Australia is significantly lower than in Canada, while the vehicles use essentially the same components, in the same space envelope. There is no technical reason that some of the design features of Australian vehicles could not be implemented by tank truck manufacturers in Canada.

An alternative approach would set an operational requirement that any tank truck carrying dangerous goods in Canada must have a roll threshold greater than a specified value. It would obviously be satisfied by a vehicle that was designed and built to meet that requirement. It would also allow a carrier to reduce the payload of an existing vehicle to meet the requirement. An operational roll threshold would have the same effect as a manufacturing standard, because any manufacturer who continued to produce tank trucks that did not meet that requirement would potentially incur liability in the event of a civil suit after a crash. Liability and liability insurance are serious matters for vehicle manufacturers. A Canadian operational requirement would cause both Canadian and U.S. manufacturers to change their designs to meet the new requirement.

Tank trucks have a very long service life. One of the vehicles tested was almost 30 years old, and another was over 20 years old. Substantial numbers of tank trucks were built in the four western provinces in response to implementation of the national standard for vehicle weights and dimensions in1989-90, and to various changes in regulations in Québec, Ontario and the Atlantic provinces since then, so are not yet half way through their service lives. So, while a minimum roll threshold for new vehicles will ultimately improve the roll threshold of the entire fleet, it may take as long as 30 years.

It is hardly possible to make any significant physical change to an existing tank truck that will increase its roll threshold. However, electronic roll stability augmentation systems now exist that can be installed on a truck, tractor, trailer, or both, when a suitable anti-lock brake system is installed. A roll stability augmentation system cannot prevent rollover, but it appears that it can provide a significant increase in roll threshold at least equivalent to, and maybe significantly greater, than what might be possible by design changes to the vehicle. Carriers that operate tank trucks typically replace tractors on a four to seven year cycle, though straight trucks have a longer life. Carriers are also required to conduct detailed inspections of tank vehicles on a specified cycle of two, five or ten years, depending on the tank specification and usage. A roll stability augmentation system could easily be installed while the vehicle is undergoing such an inspection. An operational requirement that recognizes a roll stability augmentation system could effectively upgrade the roll threshold of the entire tank truck fleet within the inspection cycle of the tank vehicles, or the replacement cycle of the power unit. It is likely that most vehicles could reach this state within ten years, rather than the 25 to 30 years that would arise if only a design standard would be used. An operational requirement allows carriers flexibility to make their own equipment decisions, based on their perceptions of the costs and benefits of modifying or upgrading a vehicle, continuing to operate it with a reduced payload, selling, retiring or down-grading it, buying a new vehicle, or others.

5 CONCLUSIONS

NRC/CSTT conducted tilt tests to determine the rollover threshold of 17 tank trucks used for highway transportation of dangerous goods, on behalf of Transport Canada’s Transport Dangerous Goods Directorate. Computer simulations were also conducted. The simulation could match the rollover characteristics and roll threshold closely for all vehicles tested, including those where any liftable axles were raised.

There appears to be consensus that the minimum roll threshold should be at least 0.40 g for any tank truck. 7 of 17 (41%) of the distinct vehicles tested here would be expected to have a roll threshold under 0.35 g when loaded to their allowable gross weight in Ontario, and 83% (14 of 17) would have a roll threshold under 0.40 g. Raising the liftable axles on a vehicle so equipped reduced its roll threshold by 0.01-0.03 g. The modest roll thresholds of the vehicles tested are partly due to the rather high gross weights allowed in Canada, and partly due to design features that elevate the tank. Two vehicles with higher roll thresholds were clearly designed for a low payload centre of gravity.

A requirement for a minimum roll threshold for new tank trucks would ultimately improve the roll resistance of the Canadian tank truck fleet, but it could take 25-30 years after the effective date of such a standard before all the fleet would be replaced. An operational requirement that dangerous goods must be shipped in a tank truck that meets a specified roll threshold, if interpreted to include a roll stability augmentation system, could effectively bring the roll threshold of the entire tank truck fleet up within ten years.

6 REFERENCES

Billing J.R. (2004). "An Assessment of Flatbed Semitrailer Roll Stability", Report CSTT-HVC-TR-060, Centre for Surface Transportation Technology, National Research Council for Transport Canada, Road Safety and Motor Vehicle Regulation, Ottawa.

Billing J.R. and Patten J.D. (2005). "An Assessment of Tank Truck Roll Stability", Report TP 14237 E, Centre for Surface Transportation Technology, National Research Council for Transport Canada, Transport Dangerous Goods Directorate, Ottawa.

Delisle G. and Pearson J.R. (1986). "Investigating Articulated Vehicle Roll Stability Using a Tilt Table", CCMTA/RTAC Vehicle Weights and Dimensions Study Technical Report Volume 7.

Dill P.A. (1985). "Static Roll Model User's Manual", University of Michigan Transportation Research Institute.

Land Transport Safety Authority (2003). "Static Roll Thresholds", http://www.ltsa.govt.nz/factsheets/13e.html.

National Road Transport Commission (2002). "An Overview of Performance–Based Standards Regulatory and Compliance Processes", Melbourne, Australia.

Roads and Transportation Association of Canada (1986). "Vehicle Weights and Dimensions Study Technical Steering Committee Report", Ottawa, Ontario.

Standards Australia International Ltd (1999). "Road Tank Vehicles for Dangerous Goods", Standard AS2809, Sydney, NSW, Australia.

Southcombe E.J., Ruhl R.L. and Kuznetsov E. (2000). "Fluid Load Analysis within the Static Roll Model", Paper 2000-01-3476, Society of Automotive Engineers Truck and Bus Meeting.

United Nations Economic Commission for Europe (2000). "Uniform Provisions Concerning the Approval of Tank Vehicles of Categories N and O with Regard to Rollover Stability", Regulation No. 111.

Winkler C.B., Blower D.F., Ervin R.D. and Chalasani R.M. (2000). "Rollover of Heavy Commercial Vehicles", Research Report RR-004, Society of Automotive Engineers.

Woodrooffe J.H.F. (2000). "Evaluation of Dangerous Goods Vehicle Safety Performance", Report TP 13678E, Report for Transport Canada, Transport Dangerous Goods Directorate, Ottawa.