National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: September 2, 2011

In reply refer to: H-11-7 through -12 and
H-10-5 and -6
(Reclassification)

The Honorable David L. Strickland
Administrator
National Highway Traffic Safety Administration
1200 New Jersey Avenue, SE
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Washington, DC 20590

On October 22, 2009, about 10:38 a.m. eastern daylight time, a 2006 Navistar International truck-tractor in combination with a 1994 Mississippi Tank Company MC331 specification cargo tank semitrailer (the combination unit), operated by AmeriGas Propane, L.P., and laden with 9,001 gallons of liquefied petroleum gas, rolled over on a connection ramp after exiting Interstate 69 (I-69) southbound to proceed south on Interstate 465 (I-465), about 10 miles northeast of downtown Indianapolis, Indiana.[1]

The truck driver was negotiating a left curve in the right lane on the connection ramp, which consisted of two southbound lanes, when the combination unit began to encroach upon the left lane, occupied by a 2007 Volvo S40 passenger car. The truck driver responded to the Volvo's presence in the left lane by oversteering clockwise, causing the combination unit to veer to the right and travel onto the paved right shoulder. Moments later, the truck driver steered counterclockwise to redirect and return the combination unit from the right shoulder to the right lane.

The truck driver's excessive, rapid, evasive steering maneuver triggered a sequence of events that caused the cargo tank semitrailer to roll over, decouple from the truck-tractor, penetrate a steel W-beam guardrail, and collide with a bridge footing and concrete pier column supporting the southbound I-465 overpass. The collision entirely displaced the outside bridge pier column from its footing and resulted in a breach at the front of the cargo tank that allowed the liquefied petroleum gas to escape, form a vapor cloud, and ignite. The truck-tractor came to rest on its right side south of the I-465 overpasses, and the decoupled cargo tank semitrailer came

[1] For additional information, see *Rollover of a Truck-Tractor and Cargo Tank Semitrailer Carrying Liquefied Petroleum Gas and Subsequent Fire, Indianapolis, Indiana, October 22, 2009*, Highway Accident Report NTSB/HAR-11/01 (Washington, DC: National Transportation Safety Board, 2011), which is available on the NTSB website at <http://www.ntsb.gov>.

to rest on its left side, near the bridge footing supporting the southbound I-465 overpass. The truck driver and the Volvo driver sustained serious injuries in the accident and postaccident fire, and three occupants of passenger vehicles traveling on I-465 received minor injuries from the postaccident fire.

The National Transportation Safety Board (NTSB) determined that the probable cause of this accident was the excessive, rapid, evasive steering maneuver that the truck driver executed after the combination unit began to encroach upon the occupied left lane. Contributing to the rollover was the driver's quickly steering the combination unit from the right shoulder to the right lane, the reduced cross slope of the paved right shoulder, and the susceptibility of the combination unit to rollover because of its high center of gravity. Mitigating the severity of the accident was the bridge design, including the elements of continuity and redundancy, which prevented the structure from collapsing.

Stability Control Systems

Stability control systems are an emerging technology that holds promise for reducing heavy commercial motor vehicle accidents by preventing untripped rollovers[2] (excessive speed in a curve), mitigating severe oversteer and understeer conditions that could lead to loss of control, and providing objective feedback to assist carriers monitor and improve driver performance.

It was not possible to determine whether stability control systems could have prevented this specific accident due to the absence of information as a result of the truck-tractor's engine electronic control module being destroyed in the fire. However, simulations conducted by the NTSB under circumstances similar to the accident indicated that a rollover stability control (RSC) system has the potential to prevent rollovers by applying the service brakes when the lateral acceleration of a simulated vehicle exceeds 0.3 *g*.

Research has found the effectiveness of electronic stability control (ESC) and RSC in reducing rollover and loss of control accidents can vary depending on the crash scenario. The combined effectiveness rates of ESC installed on class 8 truck-tractors was found to be greater (28–36 percent) than for RSC (21–30 percent).[3] A 2009 U.S. Department of Transportation (DOT) study involving tractor-semitrailers found that more overall safety benefits were provided with ESC than with RSC; 106 fewer fatalities and 4,384 fewer injuries would be expected to occur if all existing five-axle tractor-semitrailers in the United States were outfitted with ESC systems.[4] The NTSB concludes that a stability control system on the combination unit may have prevented this accident.

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[2] *Untripped* rollovers occur when tire/road interface friction is the only external force acting on a vehicle that rolls over. In contrast, *tripped* rollovers are caused when vehicles impact curbs, potholes, and guardrails or when wheel rims burrow into soft soil or pavement.

[3] *Effectiveness of Stability Control Systems for Truck Tractors*, Traffic Safety Factors, DOT-HS-811-437 (Washington, DC: National Highway Traffic Safety Administration, January 2011).

[4] J. Woodrooffe and others, *Safety Benefits of Stability Control Systems for Tractor-Semitrailers*, DOT-HS-811-205 (Washington, DC: U.S. Department of Transportation, National Highway Traffic Safety Administration, 2009).

The NTSB has long advocated the study and implementation of advanced crash avoidance technologies to assist drivers in maintaining control of commercial motor vehicles. For example, the NTSB recommended, as a result of its investigation of a 2009 bus rollover in Dolan Springs, Arizona,[5] that the National Highway Traffic Safety Administration (NHTSA) develop performance standards and ultimately require that all newly manufactured buses with a gross vehicle weight rating (GVWR) greater than 10,000 pounds be equipped with stability control systems. Separate rulemakings may be required to equip *all* commercial motor vehicles with a GVWR greater than 10,000 pounds with such systems because some vehicles have hydraulic brakes and others have pneumatic brakes, which use different components and approaches to modulate, maintain, and release the pressurized fluid or air sent to the foundation brakes to prevent wheel lockup. Therefore, the NTSB recommends that NHTSA develop stability control system performance standards for all commercial motor vehicles and buses with a GVWR greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system; and, once the performance standards have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a GVWR greater than 10,000 pounds. As a result of these new recommendations to NHTSA, the NTSB reclassifies Safety Recommendations H-10-5 and -6 “Closed—Superseded.”

The NTSB concludes that, given the long service life of cargo tanks, 25–50 years could pass before all cargo tank trailers would be equipped with stability control systems. While it is feasible to retrofit trailers with an RSC system, it is not practical to fully integrate sensors and internal communication systems on single-unit trucks and truck-tractors. Consequently, the NTSB is recommending that the Federal Motor Carrier Safety Administration (FMCSA) require all in-use cargo tank trailers with a GVWR greater than 10,000 pounds to be retrofitted with an RSC system.

Vehicle Design

Although several aspects of transporting hazardous materials on public roads are covered by Federal regulations, no current regulations address optimizing the roll stability of cargo tank motor vehicles. In the absence of requirements, there has been little improvement in the roll stability of cargo tank motor vehicles in the United States. Meanwhile, several countries have developed procedures, such as testing rollover propensity using a tilt table or conducting dynamic tests on a closed track, to objectively quantify and evaluate the roll stability of newly manufactured cargo tank motor vehicles. The NTSB concludes that the absence of regulatory guidance in the United States has discouraged proactive measures to improve the roll stability of cargo tank motor vehicles during the design and manufacturing process.

NTSB investigators used crash data from the *Cargo Tank Roll Stability Study*,[6] extracted from the General Estimates System (GES), to determine how many rollovers could be prevented annually, on average, by equipping truck-tractors with an RSC system, lowering center of gravity

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[5] *Bus Loss of Control and Rollover, Dolan Springs, Arizona, January 30, 2009,* Highway Accident Report NTSB/HAR-10/01 (Washington, DC: National Transportation Safety Board, 2010).

[6] D.B. Pape and others, Battelle, *Cargo Tank Roll Stability Study*, final report, contract no. GS23-F-0011L (Washington, DC: U.S. Department of Transportation, Federal Motor Carrier Safety Administration, April 30, 2007).

(CG) height by 3 inches, and increasing track width by 6 inches. GES crash data for 1999–2004 indicated that an average 1,265 cargo tank rollovers occurred annually, with approximately 702 (55.5 percent) of these involving a truck-tractor in combination with a cargo tank semitrailer.[7] Of the 702 average annual rollovers involving cargo tank semitrailers, approximately 37 (5 percent) could be prevented by installing a tractor-based RSC system to reduce untripped rollovers, approximately 84 (12 percent) could be prevented by lowering the CG height 3 inches, and approximately 119 (17 percent) could be prevented by increasing the track width by 6 inches. An estimated one of every four cargo tank semitrailer rollovers could be prevented (27 percent) by both nominally lowering the CG height 3 inches and increasing the track width 6 inches.

The authors of the *Cargo Tank Roll Stability Study* emphasized that improving the roll stability of cargo tank motor vehicles, by lowering CG height and increasing track width, was the only approach that would reduce tripped and untripped rollovers because the rollover involvement of heavy trucks is strongly related to their rollover threshold. Although design improvement strategies for increasing the rollover threshold of cargo tank motor vehicles have been found cost beneficial, such improvements have been slow to gain market share because of a small cost premium and thus their benefit has not been widely appreciated.[8] The safety benefits of concept cargo tank semitrailers that were unveiled in the 1980s, featuring improved roll stability and an additional axle to increase the GVWR by approximately 10 percent, did not lead to widespread changes in the design and manufacture of cargo tank motor vehicles.[9,10]

In summary, the NTSB concludes that the roll stability of cargo tank motor vehicles can be improved significantly by two design considerations: maximizing track width and selecting several available options for lowering CG height. Both of these design improvement strategies are utilized today.

Performance-Based Standards

The success of performance-based standards depends on empirically establishing a link between performance measures and accident risks.[11] NHTSA has effectively linked the rollover risk of sport-utility vehicles and other high CG vehicles to their static stability factor, the measurement of a vehicle's resistance to rollover, which led to design changes and improvements in the geometric stability and rollover resistance of those vehicles.[12] In the case of cargo tank motor vehicles, no additional data are required to establish a link between the risks associated with high CG vehicles that are prone to rollover and the release of hazardous materials. A performance-based roll stability standard for all cargo tank motor vehicles transporting

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[7] *Cargo Tank Roll Stability Study*, table 2-8, p. 17.

[8] *Cargo Tank Roll Stability Study*.

[9] L.A. Botkin, "Proposed Tri-Axle Tank Trailer Improves Stability and Productivity," *Modern Bulk Transporter,* September 1983.

[10] B. Klingenberg, G. Rossow, and R. Jacobsen, *FACT—The Freightliner/Heil Advanced Concept Truck*, Technical Paper No. 892462 (Warrendale, Pennsylvania: SAE International, 1989).

[11] *Regulation of Weights, Lengths, and Widths of Commercial Motor Vehicles,* Special Report 267 (Washington, DC: Transportation Research Board, 2002).

[12] M.C. Walz, *Trends in the Static Stability Factor of Passenger Cars, Light Trucks, and Vans*, Report No. DOT HS 809-868 (Washington, DC: National Highway Traffic Safety Administration, 2005).

hazardous materials in the United States was previously recommended by the University of Michigan Transporation Research Institute (UMTRI).[13]

The NTSB maintains that a regulation establishing minimum operational requirements for cargo tank motor vehicles may direct attention toward the efforts necessary for heavy truck and cargo tank manufacturers to build rollover-resistant cargo tank motor vehicles. The NTSB concludes that although manufacturers have the ability to improve the roll stability of cargo tank motor vehicles, little incentive exists for making improvements. Therefore, the NTSB recommends that NHTSA establish comprehensive minimum rollover performance standards, based on the least stable condition operated, for all newly manufactured cargo tank motor vehicles with a GVWR greater than 10,000 pounds. Further, the NTSB recommends that NHTSA, once the performance standards have been developed, require that all newly manufactured cargo tank motor vehicles with a GVWR greater than 10,000 pounds comply with the performance standards.

Effect of Partial Loads on Roll Stability

A partial liquid load has the potential to roll up the side of the tank and shift the CG as a vehicle negotiates a curve or if rapid steering movements are introduced. Assuming all other factors that could affect the stability of a vehicle remain constant, the rollover thresholds of cargo tank motor vehicles with fill levels of 80 and 100 percent would not differ significantly while negotiating a steady-state curve.[14] However, during a transient maneuver,[15] the lateral displacement of a partially filled tank introduces the added dimension of dynamic effects, which can cause bulk liquid to be displaced in one direction and then the other with an amplitude (resulting from a quick succession of steering inputs) that is twice the level of the steady-state amplitude.[16] Consequently, when a rapid, evasive steering maneuver occurs, the potential for rollover of a cargo tank with a fill level of 80 percent can be greater, despite a lower CG height, than for a cargo tank with a fill level of 100 percent.[17]

In this accident, the fill level of the cargo tank with 9,001 gallons of liquefied petroleum gas was approximately 78 percent by volume, which resulted in approximately 23 inches of void space between the top surface of the product (fill level) and the uppermost interior surface of the tank. Evaluating the dynamic effects of the sloshing and surging of liquefied petroleum gas within the MC331 cargo tank and its contribution to the rollover of the combination unit after the rapid, evasive steering maneuver was executed is beyond the capabilities of commercially available vehicle simulation software. Although more advanced simulations are possible, data for

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[13] R.D. Ervin, M. Barnes, and A. Wolfe, *Liquid Cargo Shifting and the Stability of Cargo Tank Trucks*, Report No. UMTRI-85-35/2 (Ann Arbor, Michigan: University of Michigan Transportation Research Institute, 1985).

[14] In a steady state curve, the steering wheel is maintained in a relatively constant position.

[15] In a transient maneuver, such as when a double lane change is quickly executed, the steering wheel is turned rapidly in one direction and then quickly reversed at an equal steer angle in the opposite direction.

[16] C.B. Winkler and others, *Rollover of Heavy Commercial Vehicles*, Research Report No. RR-004 (Warrendale, Pennsylvania: SAE International, 2000).

[17] Research Report No. RR-004.

validating a model of fluid sloshing and surging are not available, and a more precise description of the actual vehicle motion would be required to evaluate the effect of sloshing.

The Truck Trailer Manufacturers Association has long expressed concern about the practice of partial loading of cargo tank motor vehicles, stating in a 1980 technical bulletin that "a partially downloaded cargo tank will be less stable under cornering and braking conditions than an ordinary liquid tank loaded to its normal capacity."[18] Cargo tank manufacturers have also expressed concern, as reported during the August 2010 NTSB public hearing, about the practice of partially loading cargo tanks, explaining to motor carriers via letter regarding the limitations of partially loaded cargo tank motor vehicles.

The *Cargo Tank Driver Rollover Prevention Video* developed by the FMCSA, Pipeline and Hazardous Materials Safety Administration (PHMSA), and industry partners cautions drivers that sloshing can move the liquid sideways too suddenly and too strongly, causing a cargo tank motor vehicle to roll over. Additional strategies for reducing the number of cargo tank motor vehicle rollovers that result from the sloshing and surging of bulk liquid include specifying or retrofitting vehicles with high roll stiffness suspensions, subdividing the tank into separate compartments, and installing transverse and longitudinal baffles to impede the fore/aft and lateral movement of product.

Although a great deal is known about the mechanics of sloshing liquids in transportation tanks, fluid mechanics is exceedingly complex and slosh motions are difficult to generalize when wave amplitudes become severe.[19] While several studies have been conducted to learn more about the stability of cargo tank motor vehicles, few, if any, have included performing dynamic tests on a closed track to quantify the effect of partial liquid loads on the roll stability of cargo tank semitrailers. The NTSB concludes that the directional stability and rollover threshold of cargo tank motor vehicles can be degraded by the sloshing and surging of partial liquid loads. Therefore, the NTSB recommends that NHTSA evaluate the effect of emergency maneuvers on the sloshing and surging of bulk liquids that have various densities over a range of partially filled levels in a DOT specification cargo tank. The NTSB further recommends that if the results of the evaluation warrant action, that NHTSA establish and implement performance standards for mitigating the sloshing and surging of bulk liquids in all newly manufactured cargo tank motor vehicles with a GVWR greater than 10,000 pounds.

Therefore, the National Transportation Safety Board makes the following recommendations to the National Highway Traffic Safety Administration:

> Develop stability control system performance standards for all commercial motor vehicles and buses with a gross vehicle weight rating greater than 10,000 pounds, regardless of whether the vehicles are equipped with a hydraulic or a pneumatic brake system. (H-11-7) *This recommendation supersedes Safety Recommendation H-10-5.*

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[18] *MC 307 Tank Vehicles*, Technical Bulletin 81 (Alexandria, Virginia: Truck Trailer Manufacturers Association, June 16, 1980).

[19] UMTRI-85-35/2.

> Once the performance standards in Safety Recommendation H-11-7 have been developed, require the installation of stability control systems on all newly manufactured commercial vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-8). *This recommendation supersedes Safety Recommendation H-10-6.*
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> Establish comprehensive minimum rollover performance standards, based on the least stable condition operated, for all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-9)
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> Once the performance standards in Safety Recommendation H-11-9 have been developed, require that all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds comply with the performance standards. (H-11-10)
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> Evaluate the effect of emergency maneuvers on the sloshing and surging of bulk liquids that have various densities over a range of partially filled levels in a U.S. Department of Transportation specification cargo tank. (H-11-11)
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> If the results of Safety Recommendation H-11-11 warrant action, establish and implement performance standards for mitigating the sloshing and surging of bulk liquids in all newly manufactured cargo tank motor vehicles with a gross vehicle weight rating greater than 10,000 pounds. (H-11-12)

In addition, Safety Recommendations H-10-5 and -6 to NHTSA are classified “Closed—Superseded” in the “Stability Control Systems” section of the accident report’s Analysis.

The NTSB also issued safety recommendations to the DOT, PHMSA, the FMCSA, the Federal Highway Administration, and the American Association of State Highway and Transportation Officials (AASHTO). Additionally, this report reclassifies a previously issued recommendation to AASHTO.

In response to the recommendations in this letter, please refer to Safety Recommendations H-11-7 through -12 and H-10-5 and -6. If you would like to submit your response electronically rather than in hard copy, you may send it to the following e-mail address: correspondence@ntsb.gov. If your response includes attachments that exceed 5 megabytes, please e-mail us asking for instructions on how to use our secure mailbox. To avoid confusion, please use only one method of submission (that is, do not submit both an electronic copy and a hard copy of the same response letter).

Chairman HERSMAN, Vice Chairman HART, and Members SUMWALT, ROSEKIND, and WEENER concurred in the issuance of the new recommendations and the reclassification of Safety Recommendations H-10-5 and -6.

Original Signed By

By: Deborah A.P. Hersman
Chairman