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Dynamics and Roll Stability of a Loaded Class 8 Tractor-Livestock Semi-Trailer: An EDVDS Application

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ABSTRACT

Concern has been expressed for the effect of cattle movement upon the dynamic performance of the loaded Class 8 tractor-livestock trailer assembly. Loading guidelines exist for cattle that attempt to prevent injury or debilitation during transit, and literature exists on the orientation and some kinematics of loaded cattle.

Considerable literature exists on the effect of liquid slosh in tankers and swinging beef carcasses suspended from hooks in refrigerated van trailers on the dynamic response and roll stability of those vehicles. However, no research is reported on the case of a loaded livestock trailer—although it is analogized (incorrectly) to the above. The research that is outlined herein focuses specifically on loaded Class 8 tractors and livestock semi-trailers.

The authors have engaged in an extensive program involving the five following components:

1. Extensive full scale testing of loaded livestock trailers in accepted test protocols including:
    a. Tilt table tests (SAE J2180)
    b. U-turn maneuvers (SAE J2181)
    c. 200 ft. radius turns (SAE J2181)
    d. Slalom maneuver (ISO 7401)
    e. Highway Evasive maneuver (ISO 3888)
2. Driving on public roads at highway speeds
3. Simulation of the tractor-trailer using EDVDS (Engineering Dynamics Vehicle Dynamics Simulator) to perform the driving maneuvers in the computer environment.
4. Comparison to quasi-static analysis using a static roll model (SRM).
5. Analysis of videotape of cattle during test maneuvers.

Results of this research verify the stability of Class 8 livestock trailers and validate the use of EDVDS as tool for analysis.

INTRODUCTION

CLASS 8 LIVESTOCK TRAILER OVERVIEW

The Class 8 tractor-trailer is the primary mover of livestock within the United States. 48' to 53' trailer are common, with the 53' drop-center livestock trailer being popular the last few years. Vehicle widths have increased to 102". Today, depending on axle configurations and bridge law compliance, tractor-trailer weights of 96,000 lbs. are being achieved.

There exists the suggestion that a livestock trailer with an animate livestock load has the potential for load shift. Such a perception is not surprising given that the AAMVA Version 2 Commercial Driver's License Study Guide, the contents of which are adopted by all states, recognizes livestock under *"Other Cargo Needing Special Attention"* in the following manner: *"Livestock can move around in a trailer, causing unsafe handling. With less than a full load, use false bulkheads to keep the livestock bunched together. Even when bunched, special care is necessary because livestock can lean on curves. This shifts the center of gravity and makes rollover more likely."* The above description, while cautionary in value, is not specific as to what a "livestock trailer" is. They clearly vary from small single axle home-built ball-hitch trailers to the Class 8 trailers pulled by Class 8 tractors, which are the subject of this study.

In [1] the performance of a near properly loaded Class 8 livestock trailer is investigated. The Livestock Trucking Guide [2] published by the Livestock Conservation Institute (LCI) provides a guide for the packing density or floor area required per cow. A livestock trailer is considered properly loaded when it conforms to the standards published by the LCI.

The most authoritative reference with respect to livestock handling and transport is the book by that name edited by Grandin [3]. Chapter 6 is dedicated to cattle transport. With respect to over-the-road transport, some generalizations are possible which are fully discussed in [1]. Two of the primary observations:

1. No report is made of any coherent, voluntary movement of cattle.
2. No report is made of any degradation of vehicle performance due to livestock.

Published literature and ultimately the tests reported here and in [1] allow these conclusions with respect to livestock packing density:

1. Over-packing—not under-packing—promotes loss of balance and is detrimental to the well being of the cattle.
2. Packing density recommendations are required to insure humane treatment of livestock and prevent economic loss due to injury (bruising, dark cutting meat) but not to prevent degradation of vehicle dynamic performance.

USE OF EDVDS/HVE

The use of EDVDS within the HVE environment proved to be a reliable tool, not only in the primary analysis, but also in contemplation that the results would be used down the road in a courtroom setting.

The manufacturer of the trailer had found itself the defendant in litigation as a result of traffic accidents in which the tractor-semi-trailer had rolled over. In spite of the obviousness that rollover was the result of vehicular impact and not the cause of it, the plaintiffs found an expert whose causation theory was a blend of two diametrically opposed theories:

1. It is the cows who move laterally within the trailer and cause yaw instability of the tractor.
2. Cows are thrown about due to movement of the trailer.

To further compound the problem, the venue for the litigation did not embrace the requirements set for in Federal Court under the *Kumho* and *Daubert* decisions, therefore, the plaintiff's "expert" could testify on "mere subjective belief".

Clearly EDVDS cannot directly model the plaintiff expert's hypothecation, as a moving payload cannot be modeled. However, experimental testing, with videotape of cows inside during limit maneuvers, clearly showed no coherent mass center shift, and no unacceptable dynamic performance. EDVDS could be probative if one could model the trailer with a rigid load and show that its dynamics are equivalent to the real cattle-carrying trailer. In so doing the following hypothesis could be tested:

Hypothesis: Does the rigid load model produce identical results to the actual trailer?

If the results confirm the above, then it logically follows that any dynamics associated with the payload have no effect on the tractor-trailer dynamics and further confirm the observations in the videotape.

The benefits of using HVE continue:

A. EDVDS, with its high quality visualization capability will be useful in explaining to the trier of fact how the accident did and did not happen.
B. The use of EDVDS is validated for similarly loaded livestock trailers, even those only loosely in compliance with LCI loading recommendations.
C. The publication of these test results subject to peer review [1] provides substantiation of the questions that a Federal Judge is to ask of expert witness testimony before admission in a court of law in fulfillment of his duties as "gatekeeper" under the *Daubert* Doctrine. Those questions are:

   1. Testing: Has the theory been tested?
   2. Error Rate: Is the error rate or potential error rate known?
   3. Peer Review: Have the results been submitted to peer review?
   4. General Acceptance: Has the procedure received general acceptance among the testifier's professional peers (also known as the *Frye* Doctrine)?

VEHICLE CHARACTERISTICS

TRAILER

Table 1 contains dimensional and suspension data for the typical Class 8 livestock trailer investigated in this paper. The suspension is a four leaf-spring suspension as shown in Figure 1. The roll stiffness of the livestock semi-trailer suspension is found to fall within the University of Michigan Transportation Research Institute (UMTRI) range of roll stiffness data for typical semi-trailers [6], as shown in Figure 2.

Table 1. Data for a Typical Class 8 Livestock Trailer	
Overall Width (in)	102
Overall Length (ft)	50
Overall Height (ft)	13.5
Sprung Mass Center of Gravity (in)	77.4
King Pin Offset (in)	30
Suspension Roll Stiffness (in-lb/deg)	135000

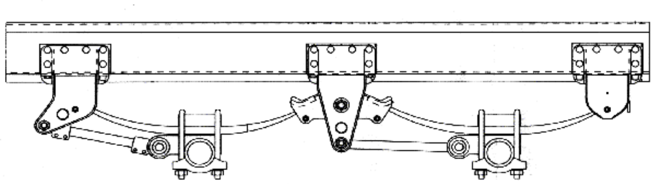

Figure 1. Typical four leaf-spring suspension

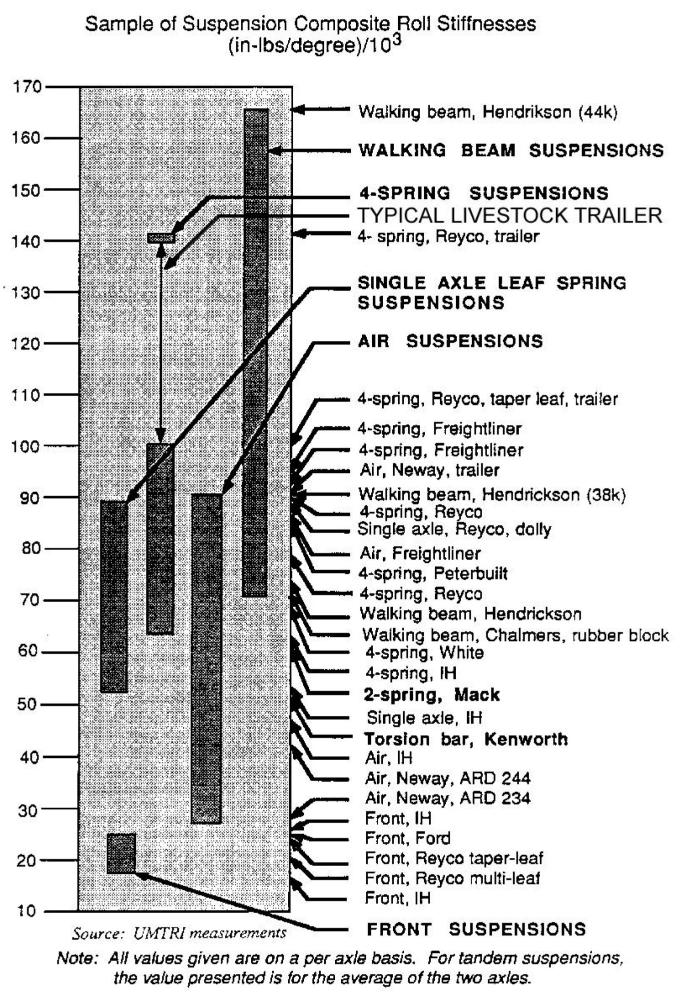

Figure 2. Typical suspension composite roll stiffness (as contained in [6])

TRACTOR

The tractor utilized for the testing described later in this paper was a 1991 Volvo-White conventional tractor with a leaf spring suspension. Typical tractor dimensions and suspensions run the full spectrum of tractors used within the livestock industry. Nothing about the empty livestock trailer dimensions and suspension, nor the choice of tractor, would distinguish it from the typical dry van trailer on the road.

STATIC LOADED CONDITION

Utilizing the LCI recommended loading procedures (which are a function of compartment floor area and cow size) the fully loaded livestock trailer may exceed a gross vehicle weight of 90,000 lbs. The vehicle as tested was 84,820 lbs and had a sprung center of mass height of 97.0 inches for the trailer and payload. Figures 3 and 4 show the upper and lower decks, respectively, of a loaded livestock trailer. Table 2 lists the center of mass height and stability ratio (T/2h) of several common trailers and loading conditions as per UMTRI [6], along with the same values for the livestock trailer as tested.

There is nothing remarkable about the stability ratio of the static Class 8 livestock trailer. The loading configuration of the Class 8 livestock trailer most closely resembles a full gross, full cube homogenous load, due to livestock characteristics and the compartmentalized design. The calculated mass center heights and stability ratio for the trailer as tested are slightly better than the full gross, full cube load and are similar to a "typical" LTL freight load.

Figure 3. The upper deck of a loaded livestock trailer

Figure 4. The lower deck of a loaded livestock trailer

Table 2. Typical Mass Center Heights and Stability Ratio for Several Trailers						
Configuration	Weight (lbs)		Mass Center Height (inches)			T/2h (Assuming 77.5" Track, Based on Composite Sprung Mass)
	GVW	Payload	Payload	Composite Spr. Mass Trailer & Payload	Composite Spr. Mass Tractor/Trailer and Payload	
Full Gross, Medium Density Freight*	80,000	52,200	83.5	80.0	75.0	0.52
"Typical" LTL Freight Load*	73,000	45,200	95.0	89.2	82.1	0.47
Full Gross, Full Cube, Homogeneous*	80,000	52,200	105.0	98.4	90.7	0.43
Full Gross Gasoline Tanker*	80,000	54,780	88.6	87.3	81.2	0.48
Livestock Trailer (As Tested)	84,820	52,320**	101.5	97.0	87.3	0.44

* As contained in [6]   ** Livestock, outriggers & instrumentation

DYNAMICS: TESTING AND SIMULATION

There is no "model" for cattle movement in vehicle simulations (EDVDS assumes a rigid payload). But as previously discussed, when recommended packing procedures are followed there is no cattle movement to model. The hypothesis to be tested is: <u>Can a difference between experimental tests with real cattle and the simulation model be found?</u> Failing this, and finding similar results, the hypothesis fails and one can establish harmony between the rigid body load simulation and real-life testing, independently confirming that there is no measurable dynamic contribution from the payload.

NATC TESTING

Testing was performed on livestock trailers at the Nevada Automotive Testing Center. The livestock loading configuration during these tests is compared to the LCI recommended loading configuration in Table 3. Figure 5 depicts the compartment numbering designation. With all compartments filled to the LCI recommended packing density, the GVW exceeds 80,000 lbs. Packing densities in the NATC tests were lower than LCI recommendations, while the gross weight of the vehicles and load still exceeded 80,000 pounds. This resulted in a conservative approach with respect to cattle movement and trailer rollover when investigating the stability of the vehicle.

Tests were performed on trailers with leaf spring suspensions and with air bag suspensions. The trailers were equipped with outriggers for safety.

Table 3. Comparison of Livestock Conservation Institute (LCI) Recommendations with NATC Loading Configuration			
Compartment (see Fig. 6)	Average Weight (lbs)	LCI Recommendation	NATC Loading
A-1	640#	9	6
A-2	640#	9	5
A-3	640#	14	12
A-4	963#	10	11
A-5	655#	14	12
A-6	835#	11	12
A-7	580#	9	6
A-8	580#	9	5

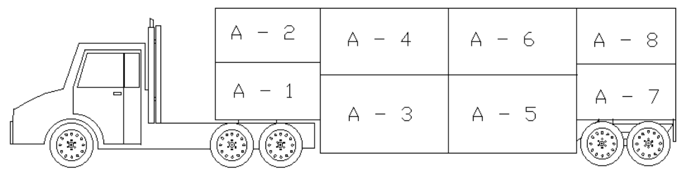

Figure 5. Compartment numbering system utilized in Table 3

<u>Tilt Table Test</u>

Tilt table tests (SAE J2180) were conducted at the NATC on the tractor and trailer while loaded with livestock (see Figure 6). However, tests were generally aborted before wheel liftoff due to agitation of the cattle. The basic assumption of the tilt table, namely that a component of the gravity force can represent a lateral acceleration without any other consequence in the interface between the load and the trailer floor is not valid with cattle. Clearly, the cattle have a sense of balance and clearly "know" that the bed of the trailer is at an extreme angle. They respond by reorientation and agitation that does not occur in a real trailer on the road. On the tilt table the angle at lift off is approximately 25 degrees, whereas the roll angle on the road even in limit maneuvers rarely exceeds 5 degrees before reaching the point of imminent rollover.

Our research indicates that use of the tilt table test for live loads must be used with great caution, if at all.

Figure 6. Screen capture from NATC videotapes showing the tilt table test

Constant Radius "Constant Velocity"

The next set of tests conducted at the NATC were the 200-foot (60.96 m) constant radius curve tests (SAE standard J2181). The combination vehicle was driven around the circular path at a constant speed to determine the steady-state roll angle and lateral acceleration at various speeds (see Figure 7). The NATC conducted the 200-foot (60.96 m) constant radius tests at speeds of 5.2, 10.5, 17.1, 21.1, and 25.9 mi/hr (8.4, 16.9, 27.5, 34.0, and 41.7 km/hr, respectively). All tests were simulated utilizing EDVDS.

Figure 7. Screen capture from NATC videotapes showing the constant radius "constant velocity" maneuver

Constant Radius "End-limit"

The second tests were the 200-foot (60.96 m) constant radius "end-limit" tests, where the speed of the combination vehicle was slowly increased until the onset of rollover. The onset of rollover is defined as the point where any one of the tractor's or trailer's tires lift off the pavement (i.e., the force on any one of the tires is zero). After the onset of rollover, the outriggers may or may not have come into contact with the ground, depending on whether the driver can provide an input to stabilize the vehicles. The purpose of the "end-limit" simulation was to compare the speed at which the trailer begins rollover in EDVDS to the speed at which the trailer begins rollover as obtained at the NATC.

Slalom Maneuver

The third tests were the slalom maneuvers (Figure 8), which are based on ISO standard 7401. The slalom maneuvers were conducted on gravel, a low friction surface. A gravel surface was used because livestock trailers are regularly driven on gravel. Cones were evenly placed along the edge of the gravel surface (see Figure 9 for course setup) so the driver knew where to provide steering inputs, and the test was conducted at several speeds until a velocity was reached where the trailer became unstable and began rollover.

The slalom tests were conducted at speeds of 11.5, 14.8, 20.0, and 21.6 mi/hr (18.4, 23.8, 32.2, and 34.8 km/hr, respectively). All test speeds have been simulated within EDVDS. The simulations were performed to compare the roll angles and lateral accelerations experienced by the trailer. The slalom was also simulated to determine the speed of incipient rollover.

Figure 8. Screen capture from NATC videotapes showing the slalom maneuver

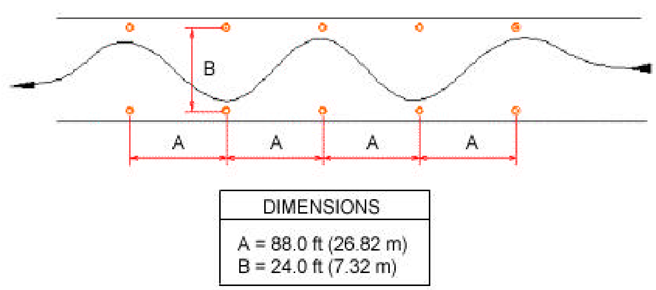

Figure 9. Slalom maneuver course setup

Highway Evasive Maneuver

The fourth set of tests was the typical highway evasive maneuver (Figure 10) based on ISO standard 3888. This test can also be described as a double lane change because the vehicle is simply providing a sharp steering input to the left and then back to the right. Cones were placed at predetermined locations (see Figure 11 for course setup) so the driver of the vehicle knew where to provide steering inputs. The vehicle was brought to a constant speed and run through the course at various speeds.

The evasive maneuvers were conducted at speeds of 34.1, 39.1, and 45.3 mi/hr (54.9, 62.9, and 72.9 km/hr, respectively), and all test speeds have been simulated within EDVDS to compare the roll angles and lateral accelerations experienced by the trailer.

Figure 10. Screen capture from NATC videotapes showing highway evasive maneuver

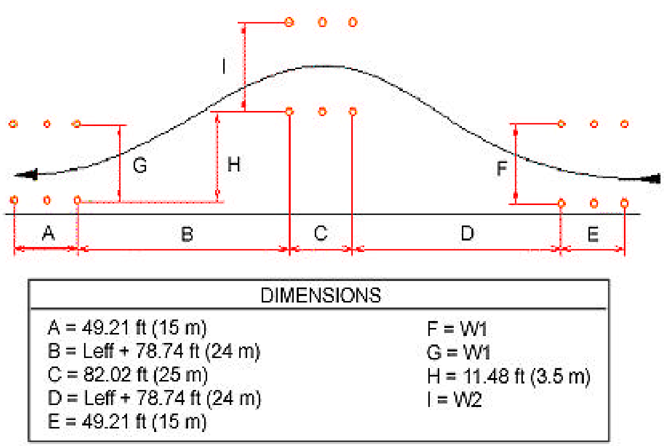

Figure 11. Highway evasive maneuver course setup

HIGHWAY TESTING

In addition to the testing performed at the NATC, a fully loaded livestock trailer was driven on a public roadway at highway speeds. The livestock trailer was equipped with cameras in the front and rear of both the upper and lower decks. The videotapes were later analyzed for any appreciable cattle movement. Figure 12 shows a frame from the videotape of the cattle coordinated with cab and external views.

Figure 12. Screen capture from highway testing showing views of the cattle coordinated with a cab view and an external view

EDVDS – Simulating the Class 8 Livestock Trailer

EDVDS (Engineering Dynamics Vehicle Dynamics Simulator) was utilized in this research to simulate the dynamic response of the Class 8 livestock trailer. EDVDS is a validated three-dimensional vehicle simulation capable of modeling combination vehicles, based on UMTRI's Phase 4 (see Day [15]).

Composite Vehicle Modeling

EDVDS minimizes the assumptions that must be made in a vehicle model. However, as with all simulations, certain assumptions must be made both in the program and by the user. Compliances significant to trailer rollover are modeled in EDVDS, with the exception of dynamic load shift as mentioned. Several secondary compliances are not modeled within EDVDS.

Tractor modeling

Tractor parameters used within EDVDS modeled the specific tractor used by the NATC. Inertial parameters were obtained by the manufacturer or were approximated. Suspension spring rates were obtained directly from the suspension manufacturer. The test tractor and trailers were equipped with 24.5-inch tires. However, the HVE database only contained 22.5-inch diameter tires, which were utilized in the model.

Trailer modeling

The trailer and load were modeled as a composite mass, as this has been determined to be the effective modeling approach to date. Inertial parameters for the composite trailer sprung mass and load, including the calculated composite CG height, were used as 'trailer' inputs. The trailer sprung mass center of gravity was calculated through analysis of each individual trailer component. The determination of the CG height for the livestock load is described later.

EDVDS is capable of modeling spring suspensions but not air bag suspensions. Therefore, the dynamic simulation comparison was limited to the NATC testing of the leaf spring suspension livestock trailer. Suspension roll stiffness, vertical stiffness and roll center height data was provided by the suspension manufacturer.

As in the case of the tractor, tire parameters were based upon data from 22.5-inch truck tires within the HVE database. The trailer was equipped with 24.5-inch tires. No significant difference in cornering stiffness between the two tire sizes was found upon review of published truck tire data. Tire compliance is considered within the tire model of EDVDS through the vertical stiffness.

Less significant roll compliances such as spring lash and fifth-wheel lash are not modeled in EDVDS.

The EDVDS model assumes that all sprung mass (trailer sprung mass and payload) is a rigid body [8]. This assumption can be an issue for flat bed trailers where torsional stiffness can affect vehicle dynamics, but a livestock trailer has been found in tilt-table tests to have negligible roll compliance [9]. The Wilson livestock trailer is manufactured using high-strength aluminum with lateral cross braces to support the two decks inside the trailer. This type of construction (the box cross section) assures minimal compliance in torsion.

Aerodynamic drag forces are also not modeled in EDVDS. It is reasonable to neglect aerodynamic drag in modeling the livestock trailer because the wind speed in actual testing by the NATC was required to be less than 10 mph and the maximum vehicle speed is approximately 45 mph. The effect of drag forces would only be significant at high speeds, but is still secondary to tire forces for investigation of dynamic response [10].

Livestock load modeling

EDVDS models the load as a static load within the trailer. As mentioned above, inertial properties for the composite trailer and load were input. However, there is no degree of freedom between the load and trailer.

Livestock center of gravity and inertial properties were calculated from the actual loading configuration used at the NATC, and by using cattle dimensions as obtained from literature [11,12].

STATIC ROLL MODEL

The Static Roll Model (SRM) [13] is used for another comparison against NATC experimental results and EDVDS simulation results for the constant radius turns (SAE J2181).

RESULTS

As shown in Table 4 there is general agreement between the SRM and the simulation model (EDVDS) at all speeds. There is a very small fixed error in the accelerations reported in the NATC tests which, given the extremely low levels of output, result in large percentage error. At measurable levels of acceleration all three produce similar results.

Table 5 shows a comparison for the results of the clockwise end-limit course for two NATC runs, the Static Roll Model, and EDVDS. The table displays the speeds at which the trailer will ultimately begin rollover for both the NATC testing and the EDVDS simulation. Peak lateral accelerations for the NATC runs are slightly higher than those resulting from the idealized input in EDVDS. Nonetheless, prediction of rollover speed using EDVDS very accurately matches experimental results (within 1.26% of the NATC average). The SRM is also very similar (within 2.5%).

Table 6 provides results similar to those of Table 6, the only difference being the direction of travel. For the results in Table 4, the trailer was driven counter-clockwise around the 200-foot (60.96 m) track, rather than clockwise.

The error presented in Table 6 when based on the average of the NATC runs is relatively high. However, when Run L1-4 is dropped, the error percentages are more consistent. Error was also calculated based on Run L1-3 only because the data for Run L1-4 seems suspect. For two clockwise runs and one counter-clockwise run, the end-limit speed was near 30 mph (48.28 km/hr), and the lateral accelerations were approximately 0.33 g's; however, Run L1-4 seems to be very low for both the lateral acceleration and end-limit speed. A question is raised whether or not the speed and lateral acceleration reported by the NATC for Run L1-4 were actually end-limits, since the lateral acceleration only reached 0.25 g's and the speed only reached 26.26 mph (42.26 km/hr). No explanation is currently available for run L1-4. Viewing the videotape for that run confirms that it is not related to payload. Error in identifying actual lift-off is the most probable explanation.

Table 4. Comparison of Trailer's Lateral Acceleration (g's) for Constant Radius U-Turn at Various Speeds (all values are steady-state)					
Speed (mph)	NATC	EDVDS	% Error	Static Roll Model	% Error
5.2	0.00	0.01	-	0.01	-
10.5	0.02	0.04	-	0.04	-
17.1	0.09	0.11	-	0.10	-
21.1	0.15	0.16	-6.67	0.15	0.00
25.9	0.25	0.23	8.00	0.22	12.00

Table 5. Comparison of Lateral Acceleration and Speed for Clockwise End-Limit Runs (all values are for zero tire force--the onset of rollover)			
	Lateral Accel. (g's)	Speed (mph)	% Error*
NATC Run L2-7	0.32	29.96	-0.89
NATC Run L2-8	0.34	30.50	0.89
NATC Average	0.33	30.23	0.00
EDVDS	0.28	29.85	-1.26
Static Roll Model	0.32	30.87	2.12

* % Error based on NATC Average Rollover Speed

Table 6. Comparison of Lateral Acceleration and Speed for Counter-Clockwise End-Limit Runs (all values are for zero tire force--the onset of rollover)				
	Lateral Accel. (g's)	Speed (mph)	% Error*	% Error**
NATC Run L1-3	-0.32	29.43	5.69	0.00
NATC Run L1-4	-0.25	26.26	-5.69	-
NATC Average	-0.29	27.85	0.00	-
EDVDS	-0.28	29.85	7.20	-1.43
Static Roll Model	-0.32	30.87	10.86	-4.89

* % Error Based on NATC Average Rollover Speed

** % Error Based on NATC Rollover Speed for Run L1-3 Only

Table 7 shows a comparison of the maximum and minimum (right and left as per SAE sign convention) lateral accelerations for the slalom maneuver.

The slalom maneuver allows the driver considerable flexibility in both steer input and consequently the actual path followed. The EDVDS steering wheel angle versus time input was matched nominally to the input of the driver exclusive of any perturbations. Nonetheless, the similarity of results found encourages the use of EDVDS to supplement or partially replace full-scale testing as well as validate the modeling approach.

Table 7. Comparison of Lateral Acceleration (g's) for Slalom Maneuver at Various Speeds				
	Max		Min	
Speed (mph)	NATC Avg	EDVDS	NATC Avg	EDVDS
11.5	0.07	0.04	-0.06	-0.06
14.8	0.12	0.17	-0.11	-0.15
20.0	0.22	0.26	-0.19	-0.27
21.6	0.28	0.27	-0.26	-0.25

Table 8. Comparison of Lateral Acceleration (g's) for Evasive Maneuver at Various Speeds				
	Max		Min	
Speed (mph)	NATC	EDVDS	NATC	EDVDS
34.1	0.13	0.23	-0.14	-0.15
39.1	0.13	0.29	-0.16	-0.24
45.3	0.14	0.26	-0.22	-0.28

Table 8 provides the maximum (right) and minimum (left) lateral accelerations for the highway evasive maneuver. The simulation attempted to duplicate the vehicle movement using the measured driver steer input. There is generally poor agreement between the lateral accelerations of the simulation results and the NATC test results. At this time no definite explanation has been determined. Differences between the tire model and the actual tires is one possibility, given the reference parameter was the instrumented driver steer inputs. However, results of the slalom tests, which also used driver steer inputs as the reference parameter, showed better agreement than the evasive maneuver.

Finally, another output of interest is the trailer's roll angle, shown in Table 9.

Table 9. Comparison of Roll Angle for Clockwise End-Limit Runs (all values are at zero-tire force)	
Source	Roll Angle (deg)
NATC Run L2-7	-25.43
NATC Run L2-8	-25.97
EDVDS	-4.09
Static Roll Model	-7.9

It is clearly seen that the roll angle obtained by the NATC is approximately 600% the value obtained by the EDVDS simulations. Since approximately the same end-limit speed was obtained from EDVDS as was obtained from the NATC, it was not known from where the discrepancy was originating. A benchmark value for the roll angle at the onset of rollover for a typical trailer was found from literature to be approximately 5 degrees [14].

The NATC video was examined once again—this time to determine whether or not the roll angle could be approximately determined visually. For an end-limit run, the camera caught the rear of the trailer just before the wheels left the ground. The scene was captured digitally by a computer and imported into AutoCAD, and lines were drawn along the side of the trailer and along the line of contact at the rear wheels. The lines were then dimensioned approximate the roll angle just prior to rollover. This frame of the NATC video and angle approximation is depicted in Figure 14. An obvious sensor error in experimental data was detected. Analysis of the videotape showed the angle at liftoff closely matched the EDVDS simulation.

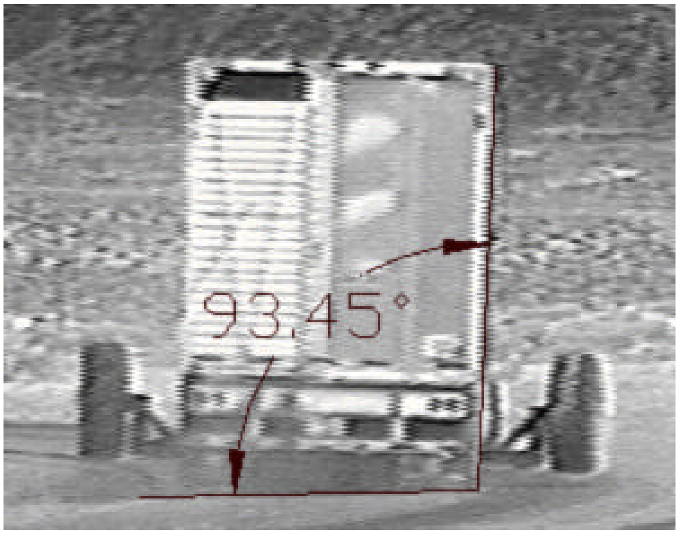

Figure 14. Approximation of roll angle just before wheel liftoff (from the NATC videotapes)

CONCLUSION

The Conclusions reached are:

1. Livestock (cattle) even when improperly loaded do not influence the unit's transient dynamics even during limit maneuvers. The use of a static roll model for limit maneuvers is a valid approach.
2. Cattle movement is voluntary by individual cow and not orchestrated or coherent nor does such movement significantly shift payload.
3. Cattle are not "thrown" or shifted even at lateral accelerations at the roll threshold. Cattle do not adversely "lean."
4. Cattle respond to platform movement (including that typically found in highway travel) by stabilizing themselves through muscular response and such "sway" movement is limited in magnitude and at a frequency considerably higher than the roll rate of the loaded trailer.
5. Standard leaf spring and air bag suspensions produce similar limit results.
6. Analogization to liquid slosh in tankers or swinging beef carcasses in refrigerated containers is conceptually incorrect and not representative of a loaded livestock semi trailer.

7. Comparison of the static roll threshold (T/2h) for a loaded livestock trailer with published data for dry vans at similar GVW demonstrates no significant difference.
8. Results of EDVDS driving simulation and static roll model (SRM) are in harmony with actual test results, validating the use of those tools for analysis and design purposes.
9. Safety concerns for a loaded Class 8 tractor-livestock semi trailer with properly or improperly loaded cattle are unwarranted.

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