Roll Stability Analysis of the TARVAN

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16. Abstract

The TARVAN is a special-purpose, highway semitrailer used by the U.S. Navy for the transportation of rocket motors and components of missles. It is typically hauled by standard commercial tractors on public highways by operators under contract to the Navy. The purpose of this project was to assess the roll stability of the TARVAN trailer fitted with a C-4, first-stage, inert rocket motor and in combination with a representative commercial highway tractor. That assessment was accomplished by direct measurement of the static roll stability of the vehicle using UMTRI's commercial vehicle tilt table facility. Four repeats of a tilt-table test of this TARVAN test vehicle showed the static rollover threshold of the vehicle to be 0.26 g. This is judged as poor stability and is expected to result in about one rollover event every million miles of highway travel. The relative importance of various facets of the TARVAN in determining the vehicle's rollover threshold are evaluated. Design changes that could improve roll stability are suggested and evaluated.

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EXECUTIVE SUMMARY

The TARVAN is a special-purpose, highway semitrailer used by the U.S. Navy for the transportation of rocket motors and components of missiles. While it is typically transported by rail car, occasionally it is hauled by standard commercial tractors on public highways. The purpose of this project was to assess the roll stability of the TARVAN trailer fitted with a C-4, first-stage, inert rocket motor and in combination with a representative commercial highway tractor. That assessment was accomplished by direct measurement of the static roll stability of the vehicle using UMTRI's commercial-vehicle tilt-table facility.

The tilt-table methodology is a physical simulation of the roll-plane experience of a vehicle in a steady turn. The vehicle is placed on a flat surface, which is very gradually tilted over in roll. The component of gravitational forces parallel to the table surface provides a simulation of the centrifugal forces experienced by a vehicle in turning maneuvers. The progressive application of these forces serves to simulate the effects of quasi-statically increasing lateral acceleration in steady turning maneuvers. The tilting process continues until the vehicle reaches the point of roll instability and "rolls over." (The vehicle is constrained by safety straps to prevent actual rollover.) The tangent of the tilt angle of the table is a good estimate of the static rollover threshold of the vehicle in gravitational units.

The Navy provided UMTRI with a complete TARVAN test vehicle composed of the

The TARVAN test vehicle in place on the UMTRI tilt table

TARVAN loaded with an inert, C-4 rocket motor and a highway tractor of the type typically used to haul the TARVAN.

Four tilt-table tests of this TARVAN test vehicle were conducted. The results of these test were as follows:

Measured Rollover Threshold of the TARVAN

Test No:	*1*	*2*	*3*	*4*	*Average*
Rollover threshold, gs:	0.258	0.259	0.260	0.258	**0.259**

The TARVAN vehicle's nominal rollover threshold of 0.26 g can only be characterized as poor and is certainly among the lower stability vehicles of the U.S. commercial truck fleet. In common service on the U.S. highway system, such a vehicle would be expected to experience a rollover about once every one million miles of travel.

The TARVAN vehicle's low level of roll stability results primarily from the high center of gravity of its rather heavy payload. The problem is aggravated by the dated, rather underspecified tire and suspension components of the TARVAN. The shock mounting system of the rocket motor carriage was *not* found to be a major contributor to the vehicle's low stability level.

Relatively modest changes in the design and specifications of the TARVAN were found to have the potential for improving the vehicle's stability level to about 0.33 g. This level of roll stability is roughly equivalent to that of the typical 5-axle gasoline tanker and implies an expectation of 0.75 rollovers per million miles. The changes considered, in order of importance, were (1) lowering the C-4 motor 6 inches, (2) using 102-inch (rather than 96-inch) wide trailer axles, (3) equipping the TARVAN with modern trailer air suspension, and (4) equipping the TARVAN with tires of appropriate size and load rating (as opposed to the underrated tires currently used).

More radical changes in the TARVAN design could raise the vehicle's rollover threshold well over 0.4 g, placing it in the better half of the U.S. commercial vehicle fleet and reducing rollover expectations to less than 0.5 events per million miles. The most important step in accomplishing this (beyond the design changes indicated above) would be lowering the payload center of gravity substantially. A drop-neck trailer design using a 3-axle suspension with very low profile tires would allow lowering the cargo center of gravity at least an additional foot. The stability of the vehicle could be enhanced further by using only tractors equipped with drive axles which are 102 inches wide.

INTRODUCTION

The TARVAN is a special-purpose, highway semitrailer used by the U.S. Navy for the transportation of rocket motors and components of missiles. While it is typically transported by rail car, occasionally it is hauled by standard commercial tractors on public highways. The purpose of this project was to assess the roll stability of the TARVAN trailer fitted with a C-4, first-stage, inert rocket motor and in combination with a representative commercial highway tractor. That assessment was accomplished (1) by direct measurement of the static roll stability of the vehicle using UMTRI's commercial-vehicle, tilt-table facility and (2) through analyses which provide an estimate of rollover risk and which describe the influence of various properties of the vehicle that serve to establish the roll stability limit.

The TARVAN, like other vehicles procured by the Navy, is subject to a minimum requirement for a static roll stability of 0.3 g lateral acceleration. Analyses conducted by the contractor responsible for the design and development of the TARVAN predict a static roll stability of the loaded TARVAN in combination with a highway tractor of 0.312 g.[1][1][2] Nonetheless, drivers who have hauled the TARVAN and Navy personnel responsible for the regular use of the TARVAN have expressed the opinion that this trailer has unusually low roll stability.

The roll stability analysis of reference [1] is, of course, approximate as are all such analyses. The analytical model is necessarily a simplification, and the parameters used in the model to describe this particular vehicle are estimates. An unfortunate fact generally applicable to all roll analyses of road vehicles is that the cumulative effect of the analytical simplifications is an overestimate of the system stability. That is, each simplification usually involves ignoring some compliance in the vehicle which is judged to have only a small effect. However, compliances are virtually *all* destabilizing, so that while the individual effects ignored may be small, their total effect may be appreciable.

Comparison with similar analyses in the literature also suggests that the analysis of the TARVAN may overestimate the vehicle stability. Specifically, Ervin predicted a static stability limit of approximately 0.25 g for a typical, five-axle, commercial tractor-semitrailer with gross weight and center-of-gravity height similar to the TARVAN.[2] (In the same publication, he showed agreement between predictions and test results to within 0.03 g, although not for this particular vehicle.)

These points suggest that it was reasonable to question the previous analysis of the static stability of the TARVAN, and that a reevaluation was warranted.

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1 In the case of a tractor semitrailer combination, roll stability can only be determined for the complete vehicle. Thus, the roll stability limit of the TARVAN alone is not a viable concept. For brevity herein, however, we will refer to the roll stability of the TARVAN, always meaning the stability of the TARVAN in combination with a representative highway tractor.

2 Numbers in brackets refer to bibliographic references given in the last section of this Statement of Work.

As implied above, the validity of the analytical approach depends on the inclusiveness of the model and the accuracy of the vehicle descriptive parameters used. Improving the analytical prediction of the TARVAN stability limit would involve adding a variety of structural compliances not previously included in the model and determining parameters for both the new and old elements of the model. These parameters could again be estimated, which would again leave the results in question, or they could be measured using the actual vehicle. This would be a lengthy and expensive process.

When the roll stability analysis of the TARVAN was first made, the vehicle was in design and did not exist. At the time of this project, however, the TARVAN was an existing vehicle. Thus, rather than redoing the theoretical analysis, the direct measurement of the TARVAN static stability was clearly more reasonable. The direct measurement has two distinct advantages: (1) it provides the "right" answer with little room for argument, and, (2) it is less expensive and time consuming for an existing vehicle than is the analysis with its attendant parameter measurement process.

THE TILT-TABLE METHOD AND FACILITY

The purpose of the tilt-table test is to estimate the static roll stability limit of the test vehicle.

The tilt-table methodology is a physical simulation of the roll plane experience of a vehicle in a steady turn. The vehicle is placed on a tilt table and is very gradually tilted over in roll. As shown in figure 1, the component of gravitational forces parallel to the table surface provides a simulation of the centrifugal forces experienced by a vehicle in turning maneuvers. The progressive application of these forces by slowly tilting the table serves to simulate the effects of quasi-statically increasing lateral acceleration in steady turning maneuvers. The tilting process continues until the vehicle reaches the point of roll instability and "rolls over." (The vehicle is constrained by safety straps to prevent actual rollover.)

When the table is tilted, the component of gravitational forces parallel to the table surface, $W \bullet \sin(\phi)$, simulates lateral forces, and the weight of the vehicle itself is simulated by the component of gravitational forces that are perpendicular to the table (i.e. $W \bullet \cos(\phi)$, where W is the weight of the vehicle and ϕ is the roll angle of the table relative to the true gravitational vector). Thus, the forces acting during the tilt-table test are *scaled down* by a factor of $\cos(\phi)$. Since the important mechanisms of actual rollover depend on the *ratio* of the centrifugal forces to the vertical, gravitational forces, it is appropriate to take the ratio of the simulated lateral acceleration forces to the simulated weight to represent lateral acceleration when interpreting the results of a tilt-table experiment. That is:

$$\mathbf{a_{ys}} \equiv \mathbf{tan(\phi)} = W \bullet \sin(\phi) / W \bullet \cos(\phi) \qquad (1)$$

where:

a_{ys}	is the simulated lateral acceleration (expressed in gravitational units)
ϕ	is the roll angle of the tilt table
W	is the weight of the vehicle.

The quality of $\tan(\phi)$ as an estimate of actual static roll stability depends, in part, on how closely $(\cos\phi)$ approximates unity. In the tilt-table experiment, both the vertical and lateral loading of the vehicle are reduced by the factor $(\cos\phi)$ relative to the loads they are meant to represent. Because of the reduced vertical loading, the vehicle may rise on its compliant tires and suspensions relative to its normal ride height, resulting in a higher center of gravity position and, possibly, an unrealistically *low* estimate of the static roll stability limit. At the same time, static lateral loading is also reduced by the factor $(\cos\phi)$. This may result in compliant lateral and roll motions of the vehicle that are unrepresentatively small, tending to produce an unrealistically *high* estimate of the static roll stability limit. The fact that these two influences tend to cancel is clearly advantageous. More importantly, for the moderate angles of tilt required to test large commercial vehicles,

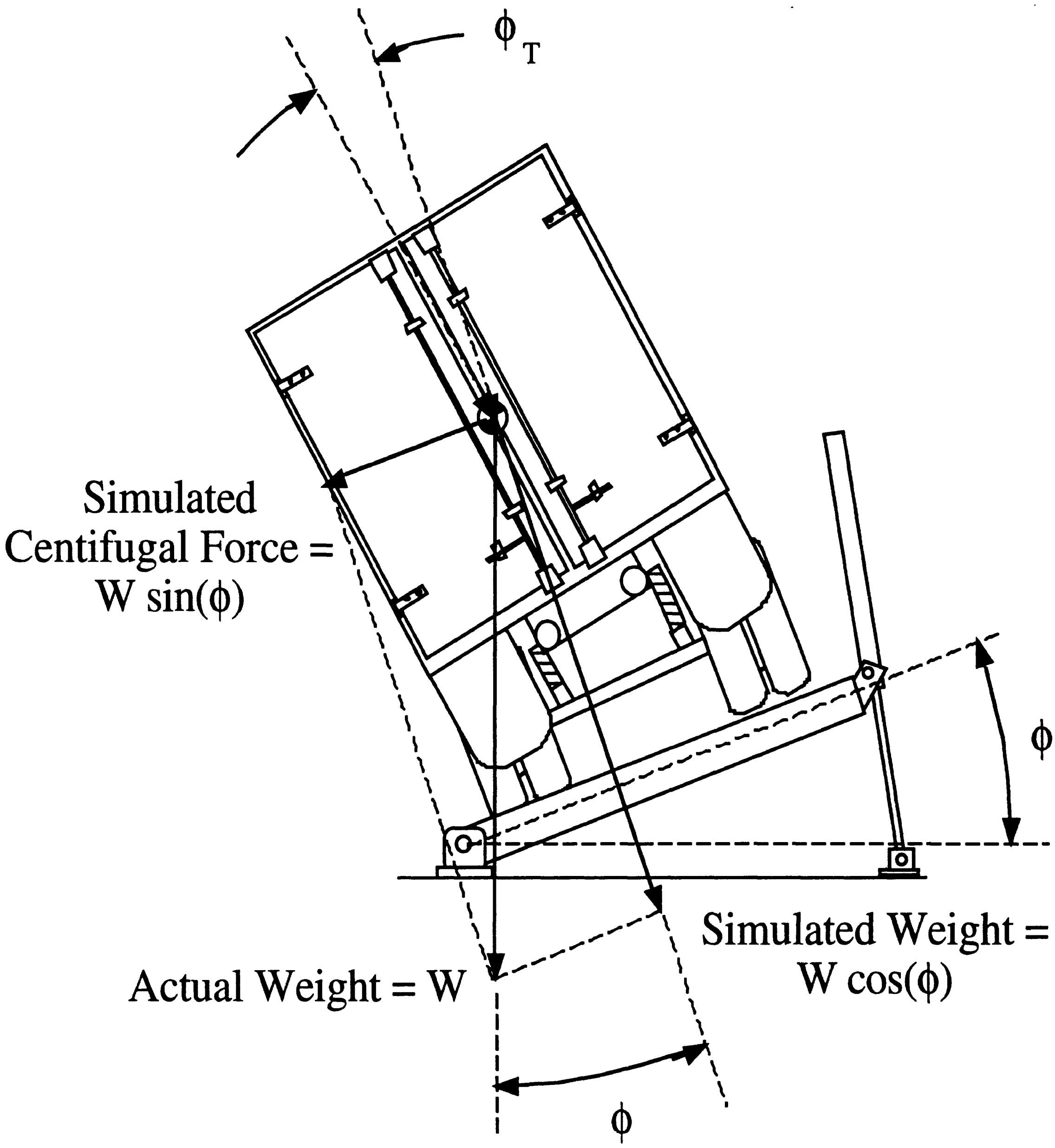


Figure 1. Schematic diagram of a tilt-table test

cosϕ remains sufficiently near to unity such that accurate representations of all loadings are maintained. (At a tilt angle simulating 0.26 g lateral acceleration, cosϕ is 0.97.)

A second error source in this physical simulation methodology involves the *distribution* of lateral forces among the tires of the several axles of the vehicle. Lateral forces developed at the tire-road interface must, of course, satisfy the requirements of static equilibrium of lateral force and yaw moments acting on the vehicle. For the tractor semitrailer combination vehicle, the lateral force and yaw moment equilibrium requirements provide three equilibrium equations, but the existence of five axles (in the case of the TARVAN vehicle) implies that the system is statically indeterminate. Thus the distribution of lateral reaction forces among the five axles is partially dependent on the lateral compliance properties of the tires and suspensions. The compliance properties that are in play while the vehicle is sitting on the tilt table are not precisely those that are in play while the vehicle is in motion on the road. The significance of this error source is dependent on axle location, and the similarity, or lack thereof, of geometry among the redundant axles and suspensions. For the TARVAN vehicle, the close spacing and geometric similarity of the two axles of each tandem suspension tend to minimize these errors.

A third error source lies in the side slip angle of the tractor and the yaw articulation geometry of the vehicle. Although tilt-table experiments are conducted with these two yaw plane angles at zero, the negotiation of real turns at significant speed generally implies the existence of small, non zero yaw plane angles. Some reflection on this matter reveals that, in real practice, static rollover threshold, as measured by lateral acceleration, varies somewhat as a function of turn radius, since turn radius, in part, establishes these angles. In this light, the zero yaw angle condition is simply seen as one of many possible test conditions—certainly the one most easily implemented.

As shown in the brochure appended to this report, the UMTRI tilt table consists of five individual table units. Each of these units supports one axle of the test vehicle. Properly located and acting in concert, these five units provide the capability to conduct experiments on any commercial vehicle of up to five axles, regardless of overall length or the unit configuration.

Each table unit is a 10-inch high weldment with a 30-inch by 10-foot surface which provides the simulated ground plane for one axle. This surface is covered with unflattened expanded metal, which provides a powerful gripping action between the tires and the simulated ground, preventing the tires from slipping sideways during testing.

One end of each table unit pivots about a fixed axis, oriented parallel to the longitudinal axis of the vehicle, while the other end is supported by an hydraulic lifting cylinder. The cylinders have a stroke of 54 inches, which allows for tilting through 25.6 degrees and attaining a maximum simulated lateral acceleration of 0.48g.

In setting up for a particular vehicle, the fixed axes of the five tables are carefully aligned and leveled. During an experiment, the tilt angles of the five tables are maintained equal within a total span of 0.2 degrees, or within about 0.004 g, simulated. Rollover threshold is defined as the weighted (by axle load) average of the tangent of the table angles when roll instability of the vehicle occurs.

Table-tilt angles are measured using electronic inclinometers. The instant of instability is identified through the use of contact switches which identify the points of liftoff of the tires of the several axles of the vehicle. (Tires of the tractor steer axle are not allowed to lift. Roll instability is virtually always reached prior to the lift of this axle.) The test vehicle is instrumented with a variety of inclinometers and linear potentiometers to measure various significant compliances within the vehicle. Data recording and table control are handled by a PC-based data acquisition and control system.

THE TEST VEHICLE

The Navy provided both units of the test vehicle: the TARVAN trailer and a highway tractor of the type usually used to haul the trailer. The TARVAN trailer was delivered complete with a C-4, inert, rocket motor along with the motor support dolly, tracks and the restraining fixtures normally used in shipment.

The test vehicle is pictured in figure 2, and the units of the vehicle are identified below.

Tractor:

Operator: DIABLO Transportation, Inc.
Manufacturer: Peterbilt (Division of PACCAR)
Model: 379
VIN #: 1XP-5DB9X-6-RD348797
GVWR: 52,000 pounds
Manufactured: November, 1993
Front suspension: single-axle leaf spring
Rear suspension: tandem-axle air suspension
Test weight: 20,780 pounds
Fuel load: approximately one-half

Figure 2. The test vehicle in place on the UMTRI tilt table

Trailer:

Operator: U.S. Navy
Manufacturer: UTILITY Trailer
Model: 45-foot van
VIN #: 7L0 3047 002 VS2R
GVWR: 50,000 pounds
Manufactured: 1970
Suspension: tandem-axle, four-leaf spring
Test weight: 72,723 pounds

The vehicle was equipped with a variety of tires, which are identified in table 1. Table 1 also identifies the manufacturers' recommended inflation pressure and rated tire load carrying capacity.

The actual load condition of the vehicle as tested is given in table 2. Note that the vehicle is slightly heavier on the right side than the left. Therefore, the vehicle was tested for rollover toward its right side, since this weight distribution implies that this would be the less stabile direction.

The tractor was an obviously new and well maintained vehicle, generally appropriately equipped for hauling a relatively heavy load with a high center of gravity like the TARVAN and its cargo. The trailer, on the other hand was rather old with dated components, generally underspecified for the job within the context of current highway transport technology. More substantive commentary on these vehicle units is included in the discussion of potential improvements of the TARVAN.

The test vehicle was instrumented with several inclinometers and linear potentiometers in order to monitor its various compliant responses during the test. The purposes and nature of the vehicle instrumentation is indicated in table 3.

Table 1. Tires of the TARVAN test vehicle

Position†	*Brand*	*Model*	*Size*	*PSI*	*Load Rating*
1.1	Goodyear	G-259	11R24.5 G	105	6040
1.2	Goodyear	G-259	11R24.5 G	105	6040
2.1	Michelin	High Torque	11R24.5 G	100	6000
2.2	Michelin	High Torque	11R24.5 G	100	6000
2.3	Michelin	High Torque	11R24.5 G	100	6000
2.4	Michelin	High Torque	11R24.5 G	100	6000
3.1	Michelin	High Torque	11R24.5 G	100	6000
3.2	Michelin	High Torque	11R24.5 G	100	6000
3.3	Michelin	High Torque	11R24.5 G	100	6000
3.4	Michelin	High Torque	11R24.5 G	100	6000
4.1	Multi Miler	Premium Super Highway HD	10:00x20 F	75	4760
4.2	MRF	Tiber Highway	10:00x20 F	75	4760
4.3	Goodyear	Super Hi Miler	10:00x20 F	75	4760
4.4	MRF	Tiber Highway	10:00x20 F	75	4760
5.1	Goodyear	Hi-Miler CS	10:00x20 F	75	4760
5.2	Bridgestone	K-Miller	10:00x20 F	75	4760
5.3	Bridgestone	K-Miller	10:00x20 F	75	4760
5.4	KUMH	Highway 355	10:00x20 F	75	4760

† Axle number from front followed by left-to-right position on axle.

Table 2. Test vehicle loading

Combination Vehicle Wheel Loads, pounds			
Axle	*Left*	*Right*	*Total*
1	5,449	5,14	10,863
2	10,980	11,660	22,640
3	10,035	10,140	20,175
Tractor	26,464	27,214	53,678
4	10,300	11,340	21,640
5	8,865	9,320	18,185
Trailer	19,165	20,660	39,825
Total Vehicle	45,629	47,874	93,503

Table 3. Test vehicle instrumentation

Motion	*Linear Pot*	*Inclinometer*
Lateral motion of motor, front reference	1	
Lateral motion of motor, rear reference	1	
Roll motion of front motor reference		1
Roll motion of rear motor reference		1
Roll motion of trailer chassis @ 5th wheel		1
Roll motion of trailer chassis @ trailer suspension		1
Roll motion of tractor chassis @ 5th wheel		1
Lateral motion of reference tractor axle (#2)	1	
Lateral motion of reference trailer axle (#5)	1	
Roll motion of reference tractor axle (#2)		1
Roll motion of reference trailer axle (#5)		1
	4	7

TEST RESULTS AND ANALYSIS

Four repeats of the tilt-table test of the TARVAN vehicle were conducted. Figures 3, 4 and 5 show various views of the test vehicle at the completion of one of the tests. In these photos, the tilt angle of the table is slightly less than 15 degrees. The vehicle has exceeded its roll stability threshold and, as a result, all of the tires on the high side of the tractor drive axles and trailer axles have lifted off of the table surface. The vehicle is being restrained from rolling over completely by restraining straps applied to its wheels.

ROLLOVER THRESHOLD

The rollover thresholds determined in the four tests of the TARVAN are given in table 4. The mean of the four results is 0.259 g with a 90 percent confidence interval of 0.001 g.

Table 4. Measured rollover threshold of the TARVAN test vehicle

Test No:	*1*	*2*	*3*	*4*	*Average*
Rollover threshold, g's:	0.258	0.259	0.260	0.258	0.259

Figure 3. The TARVAN at the completion of a tilt test

Figure 4. Trailer tires have lifted off the tilt-table surface.

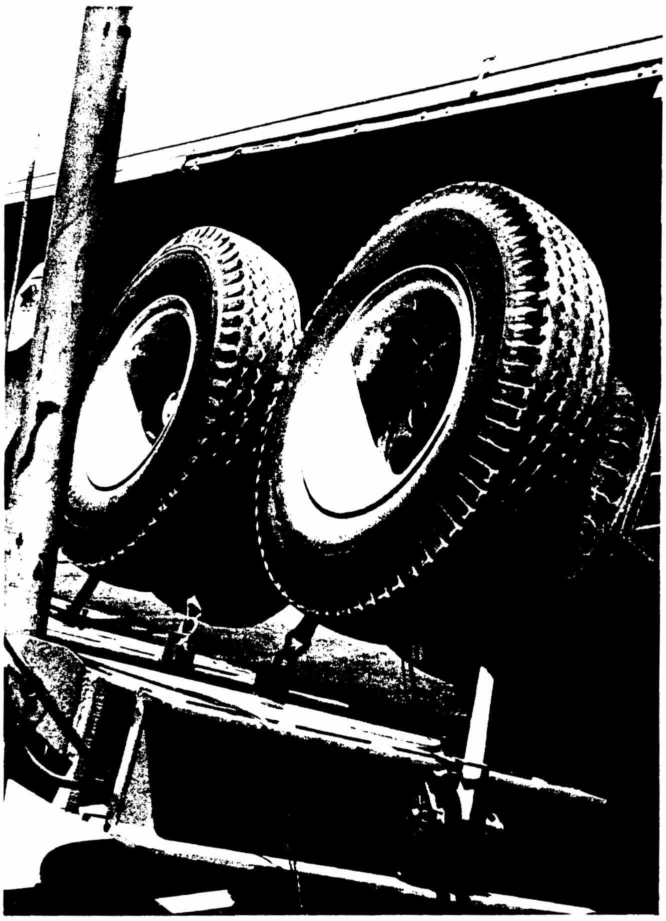


Figure 5. Safety straps prevent the test vehicle from actually rolling over.

ANALYSIS

The rollover threshold of the TARVAN test vehicle (as with any vehicle) is established by two major mechanisms. The most important is the ratio of center-of-gravity height (H) to half-track width (T/2). If the vehicle were perfectly rigid, this ratio (T/2H) would be equal to the rollover threshold of the vehicle in gravitational units of lateral acceleration.

However, the vehicle is not rigid. Its compliances result in a lean toward the outside of turn due to lateral acceleration. This lean results in the vehicle center of gravity shifting outward relative to its track (ΔY), effectively reducing the "half-track" in the rollover direction. Thus vehicle compliances virtually always reduce the actual rollover threshold of the vehicle relative to the rigid-vehicle estimate of T/2H to the lesser value of $(T/2-\Delta Y)/H$

Figure 6 is a "stiffness" plot for the overall vehicle system during one of the four tests. The vertical dimension of the graph is the simulated lateral acceleration—the "force"—and the horizontal dimension is the deflection of the vehicle center of gravity, ΔY. A rigid vehicle would produce a plot that was simply a vertical line on the y-axis. Since the vehicle is compliant, the plot shows less than infinite stiffness by sloping to the right. Events during the test that result in changes of the system stiffness are reflected in changes in slope of the plot.

As the test begins (lower left), the system is at its stiffest. All tires are on the ground, meaning all suspension stiffnesses are in play. Coulomb friction in the leaf springs cause the suspensions to be at their stiffest. Early in the test suspension friction is overcome and by about 0.07 g of lateral acceleration, the system has become a little more compliant.

At about 0.23 g, two very significant lash elements are crossed. The four-spring trailer suspension includes a substantial amount of vertical lash in the way the leaf springs are restrained. As the trailer leans, the high-side spring passes from compression to tension and moves through this lash. At the same time, the trailer begins to "roll off" the tractor and a vertical lash at the fifth wheel coupler opens up. (See figure 7.) This event results in about a 2-inch shift of the center of gravity toward rollover with no accompanying increase in stabilization by the suspension.

During, and right at the completion of the lash, the high-side trailer tires lift from the table surface (axles 4 and 5). Since the trailer suspension is now removed from the system, the system stiffness is less than it was earlier in the test.

Finally, at about 0.26 g, the tractor drive axle tires lift off and the remaining stiffness of only the tractor steer axle is not sufficient to stabilize the vehicle. The horizontal slope of the data plot at this point implies instability and rollover.

Note that at the final liftoff event (axle 2), ΔY exceeds 13 inches. Since the effective half-track of this vehicle is only about 36 inches, this means that roughly one third of the potential stability of the vehicle is lost to compliance.

Figure 8 is a column graph which indicates the relative importance of the various elements of the TARVAN system which together, establish its rollover threshold of 0.26 g.

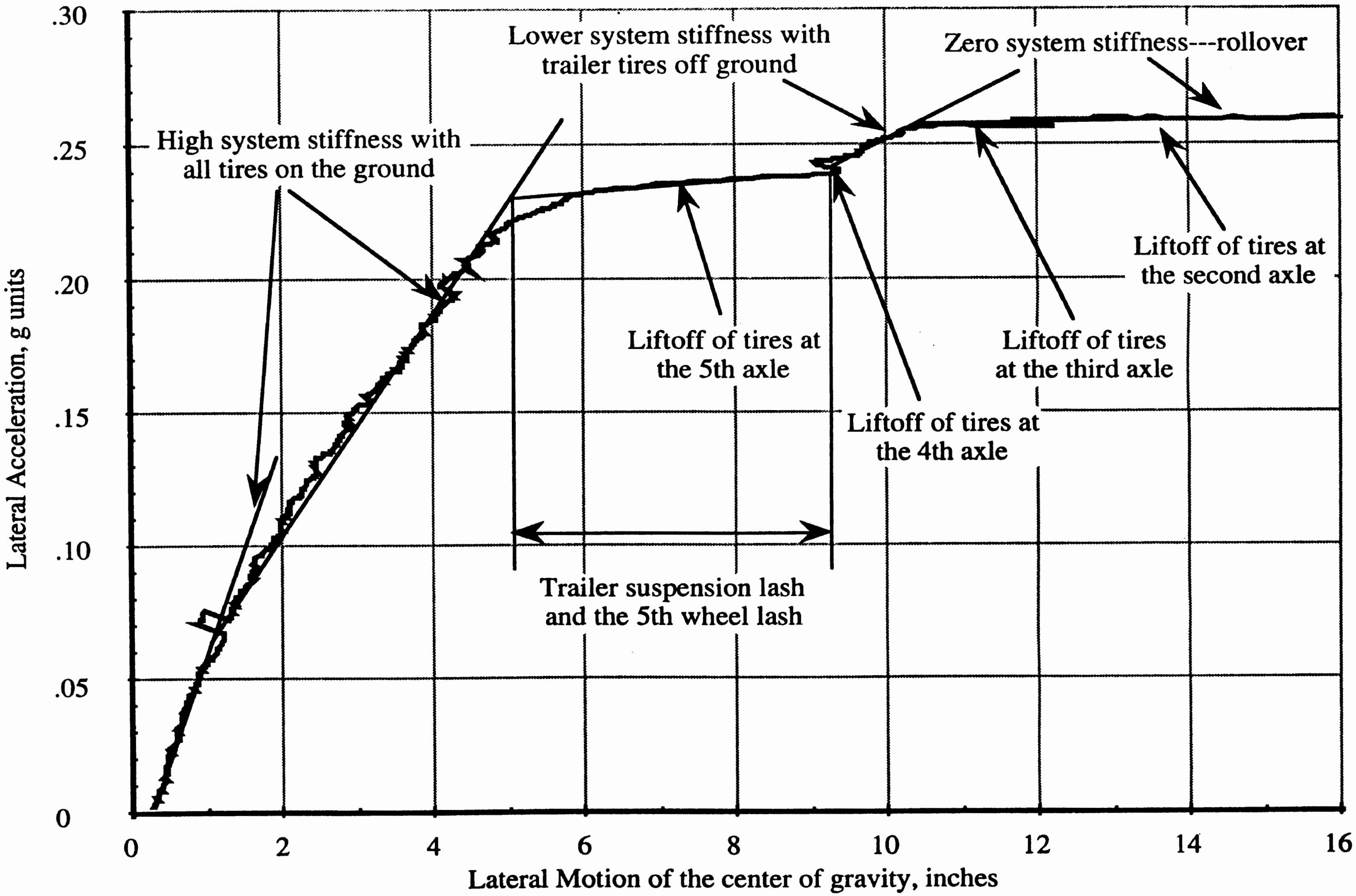


Figure 6. Vehicle system stiffness plot from a tilt table test of the TARVAN

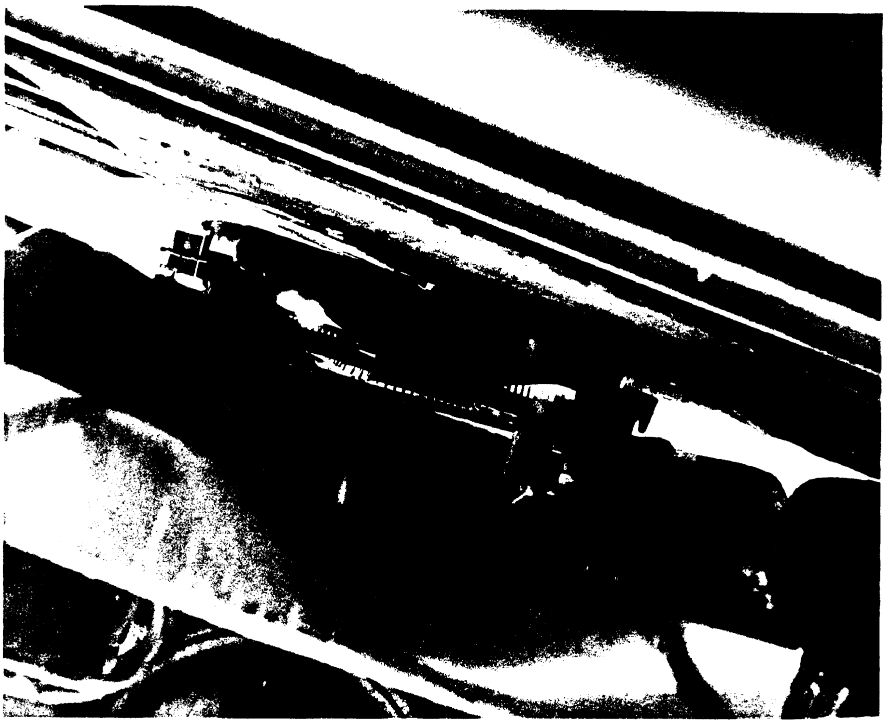


Figure 7. Fifth-wheel lash is apparent when the trailer attempts to "roll off" the tractor.

The plot is derived from an analysis of the various internal compliances of the vehicle, which can be discerned from the instrumentation listed in table 3.

If the TARVAN, its tractor, and its load were rigid, the vehicle would have a rollover threshold exceeding 0.4 g. The compliance represented in tire deflections reduces this to 0.34 g. Suspension compliance (roll and lateral, but not lash) reduce this further to 0.30 g. Combined suspension and fifth-wheel lash drop the threshold to slightly more than 0.26 g. The compliance of the rubber motor mount appears to have only a small influence relative to the compliances of the vehicle itself, but causes an additional small degradation to the final rollover threshold value of just under 0.26 g.

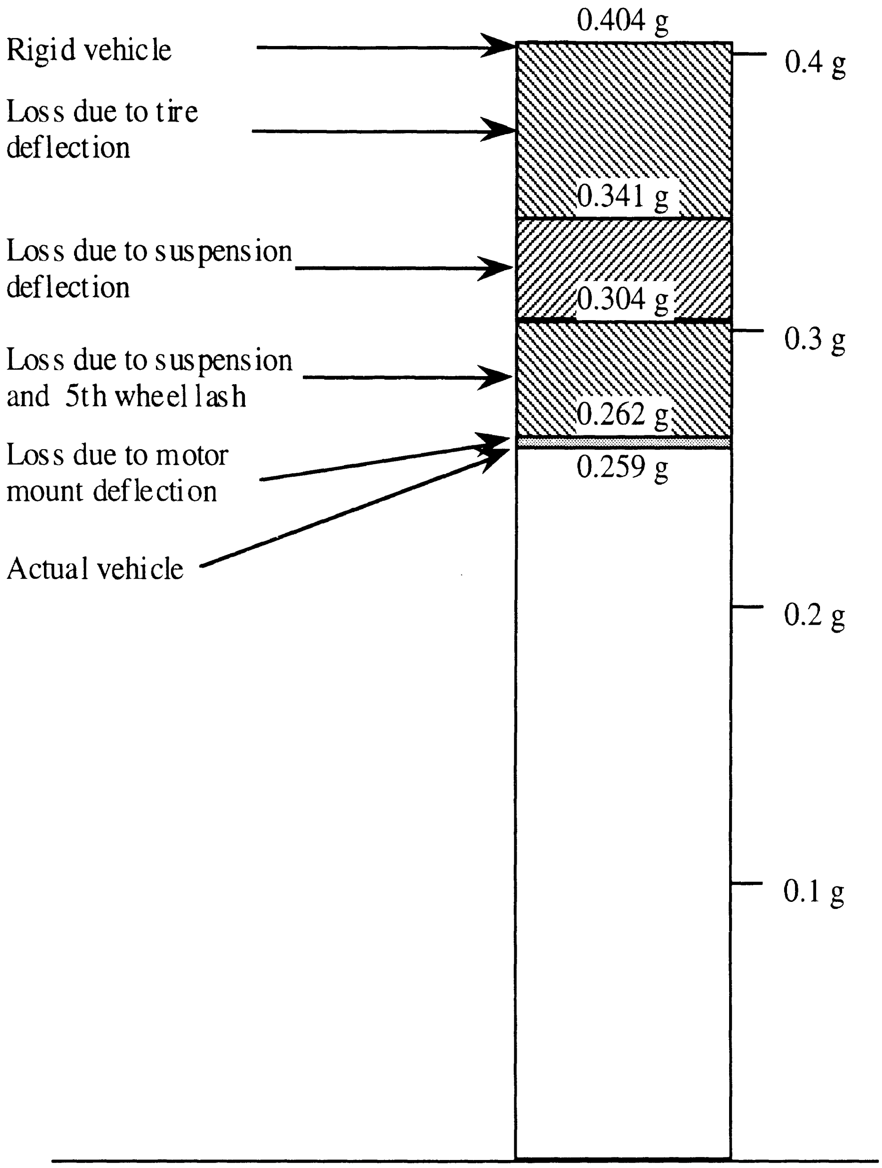


Figure 8. The contribution of various elements of the vehicle to the roll stability level of the TARVAN

POTENTIAL IMPROVEMENTS OF THE TARVAN

As noted earlier in this report, the test tractor was an obviously new and well maintained vehicle, generally appropriately equipped for hauling a relatively heavy load with high center of gravity like the TARVAN and its cargo. The TARVAN itself however, was rather old with dated components, generally underspecified for the job within the context of current highway transport technology. Specific items of interest are:

- The rocket motor appears to sit higher in the trailer than necessary. A few inches of clearance exist between track structure and dolly which do not appear necessary. A dolly design more attentive to keeping the motor low could gain a few more inches.
- The trailer axles are 96 inches in overall width. This was typical for the time of manufacture of the TARVAN. However, since the passage of the Surface Transportation Act of 1982, which allowed an increase in overall vehicle width, the industry has largely moved to 102-inch-wide trailer axles, which provide greater roll stability.
- The trailer suspension is an older, four-leaf-spring design. This suspension, while providing reasonable levels of nominal roll stiffness, also has a significant amount of vertical lash in the leaf spring retaining fixtures. As mentioned in the previous section, this lash serves to lower the rollover threshold of the vehicle. More recent designs of this style of suspension reduce the amount of lash, and modern trailer air suspensions eliminate lash all together while providing high roll stiffness.
- The trailer tires are of older bias-ply design and are undersized for the load. The bias ply tire designs used on this trailer are unusual in today's practice, having generally been supplanted by radial tires. Radials generally provide better handling properties and better fuel mileage (neither of which are at issue in this study). Further, the rated load-carrying capacity of the 10:00x20 F size tires used on the trailer is not adequate for the actual operating load. The rated load of the eight trailer tires (in dual tire configuration) sums to 38,080 pounds. The operating load of the trailer suspension, as indicated in table 2, is 39,825 pounds. More to the point than the issue of a specific limit is the general fact that tires of a higher load rating will generally provide higher vertical stiffness and, thus, more roll stability.

These four items alone offer potential for significant improvement in roll stability of the TARVAN without radical redesign. Figure 9 expands on the presentation of figure 8 to compare the existing TARVAN with a redesigned vehicle based on these four potential improvements.

Changing to 102-inch trailer axles raises the rigid-body stability by 0.02 g. Lowering the motor 6 inches gains another 0.02 g, elevating the rigid-body stability to 0.44 g.

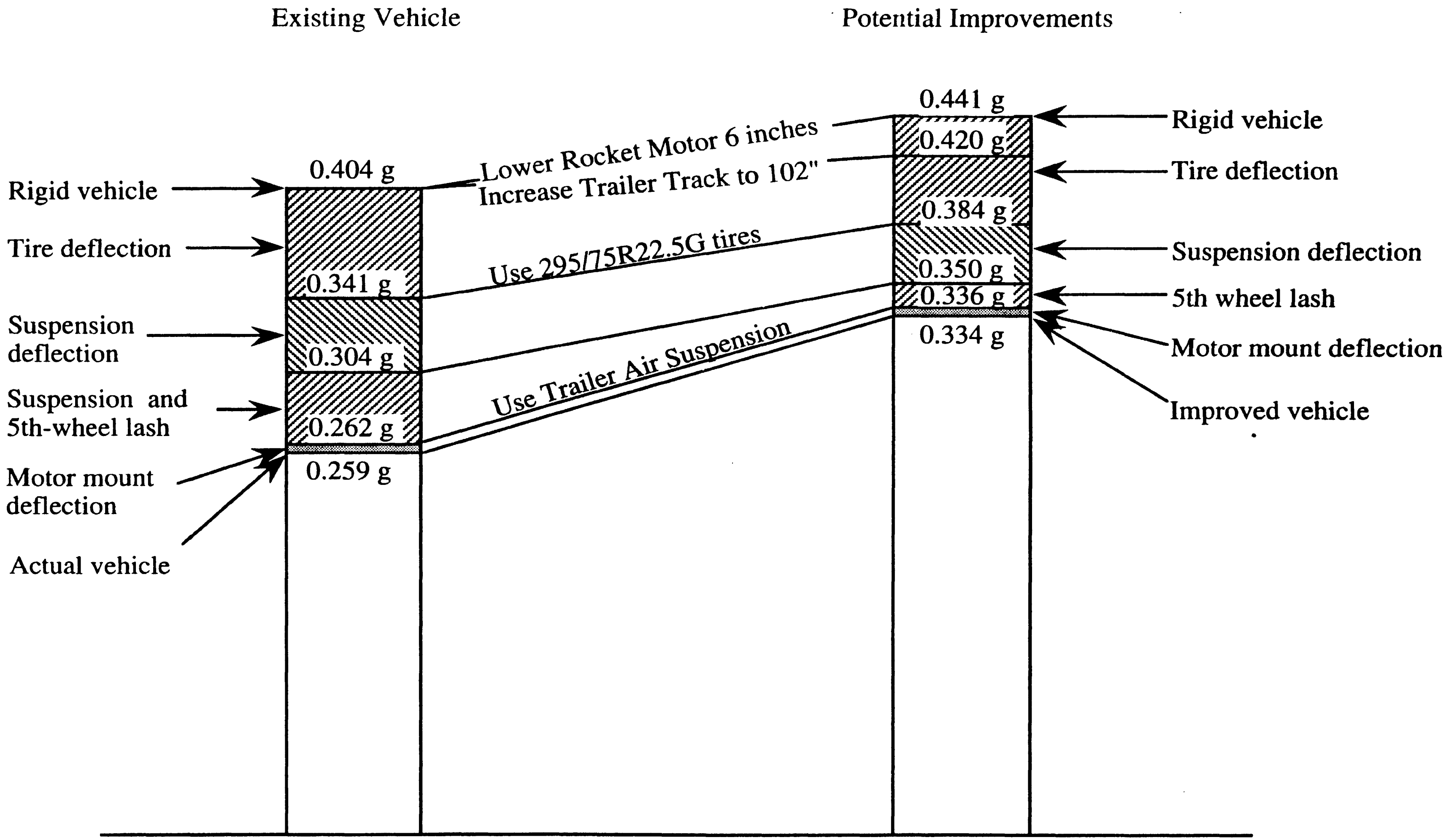


Figure 9. Potential roll stability improvements through minor changes to the TARVAN design

Changing to a modern G-range tire could provide a modest improvement of about 0.01 g (an 0.057 g degradation of the rigid system compared with 0.063g).

Replacing the existing trailer suspension with a modern air suspension would be relatively powerful. Eliminating the trailer suspension lash in this way could improve rollover threshold by about 0.03 g. (Reducing fifth wheel lash could provide still more improvement.)

As is virtually always the case in dealing with roll stability, each change appears to be minor, but the sum of these changes results in the significant improvement of rollover threshold from 0.26 g to 0.33 g.

These suggested changes are rather minor. More radical steps could lead to much greater improvements. The most powerful would be a very substantial lowering of the TARVAN center of gravity. Perhaps the next generation of TARVAN could be equipped with a 3-axle suspension using the very low profile tires typically seen on moving-van trailers. If combined with a drop-neck trailer design, the load floor of the TARVAN could be lowered a foot or more.

Unlike trailers, the vast majority of modern tractors are still manufactured with 96-inch wide running gear. (It is far more expensive to change the width of drive axles than trailer axles.) However, most U.S. truck manufactures do offer 102-inch wide drive axles as an option. Tractors hauling TARVANS could be required to use 102-inch drive axles to provide another improvement to roll stability.

These changes, along with the others discussed previously, could elevate the TARVAN's stability to a level well above 0.4 g—probably in the vicinity of the median of the U.S. commercial vehicle fleet.[3]

[3] This is an educated guess by the author, and is not substantiated by objective data.

SAFETY SIGNIFICANCE OF THE ROLL STABILITY OF THE TARVAN

The final section of this report seeks to put the findings of a physical test into the context of safety on the nation's highway system.

Clearly we expect a relationship to exist between the physical measure of rollover threshold and the occurrence of rollover accidents. Figure 10 is a plot of UMTRI's best understanding of this relationship.[3] It is based on analyses of large-scale data bases of national accident statistics. Accidents involving only dry-freight vans of the general configuration of the TARVAN (that is, 5-axle, tractor-semitrailer combinations using nominal 45-to-48-foot van semitrailers) were used to create this curve. The reader should understand that the curve is *not* precise. A good deal of engineering judgment was required to develop the curve, since accident data sources typically do not include the detail needed to firmly establish roll stability of the accident vehicle. Nevertheless, we hold a high level of confidence in the basic form of the relationship. That is, the relationship is highly nonlinear, and the sensitivity of rollover occurrence to physical stability increases dramatically among lower stability vehicles.

Four vehicles are identified along the curve: (1) the TARVAN test vehicle, (2) the modestly improved TARVAN vehicle of figure 9, (3) a typical, 5-axle gasoline tanker from the U.S. fleet, and (4) a typical, 5-axle, dry-freight tractor semitrailer. (The level of roll stability of the latter vehicle, in particular, represents the judgment of the author.)

The messages of figure 10 are:

- **The roll stability of the TARVAN as tested is *poor*.** In normal operation in the U.S. highway environment, this vehicle could be expected to experience rollover about once per million miles, or about twice as often as a typical vehicles of the U.S. commercial vehicle fleet.

- **Modest improvements in the TARVAN design could result in substantial reduction in rollover risk.** Such improvements would make the TARVAN comparable to the 5-axle tanker commonly use to move refined petroleum products in this country.

- **More radical redesign of the TARVAN could reduce rollover risk to less than half of the current level.** The changes envisioned here are substantial, but are still very straightforward in the context of current technology. They could result in a vehicle whose roll stability lies in the better half of the U.S. commercial vehicle fleet.

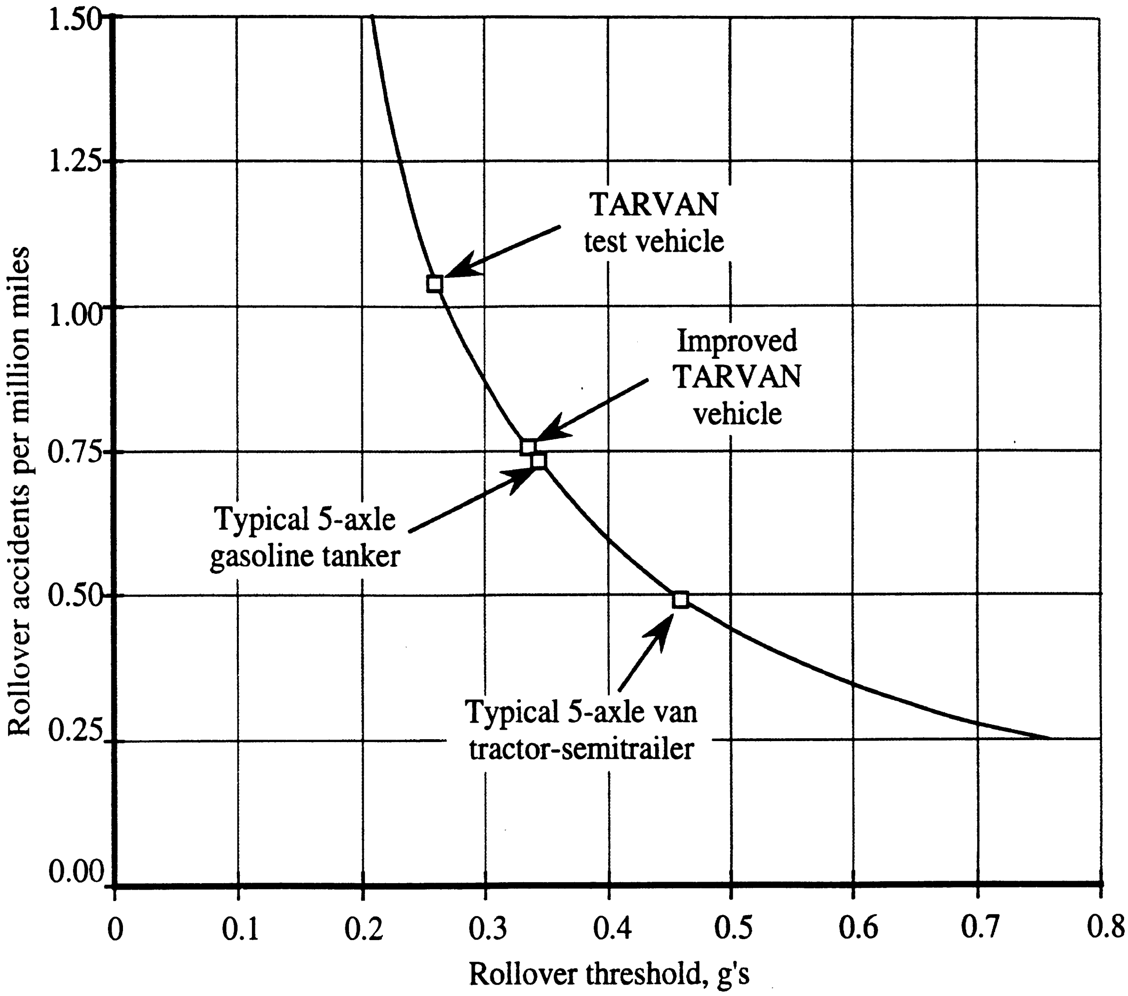


Figure 10. Estimated rollover accident rate as a function of rollover threshold

REFERENCES

1. K.R. Block to L.A. Powell. *Stability evaluation of road transport systems for C3/C4 motors.* Lockheed report IDC LAD/2628. December 21, 1989.

2. Ervin, R.D. *The influence of size and weight variables on the roll stability of heavy duty trucks.* 28 p. Presented at the Society of Automotive Engineers, West Coast International Meeting. Vancouver, British Columbia, Canada. Report No. SAE 831163. August, 1983.

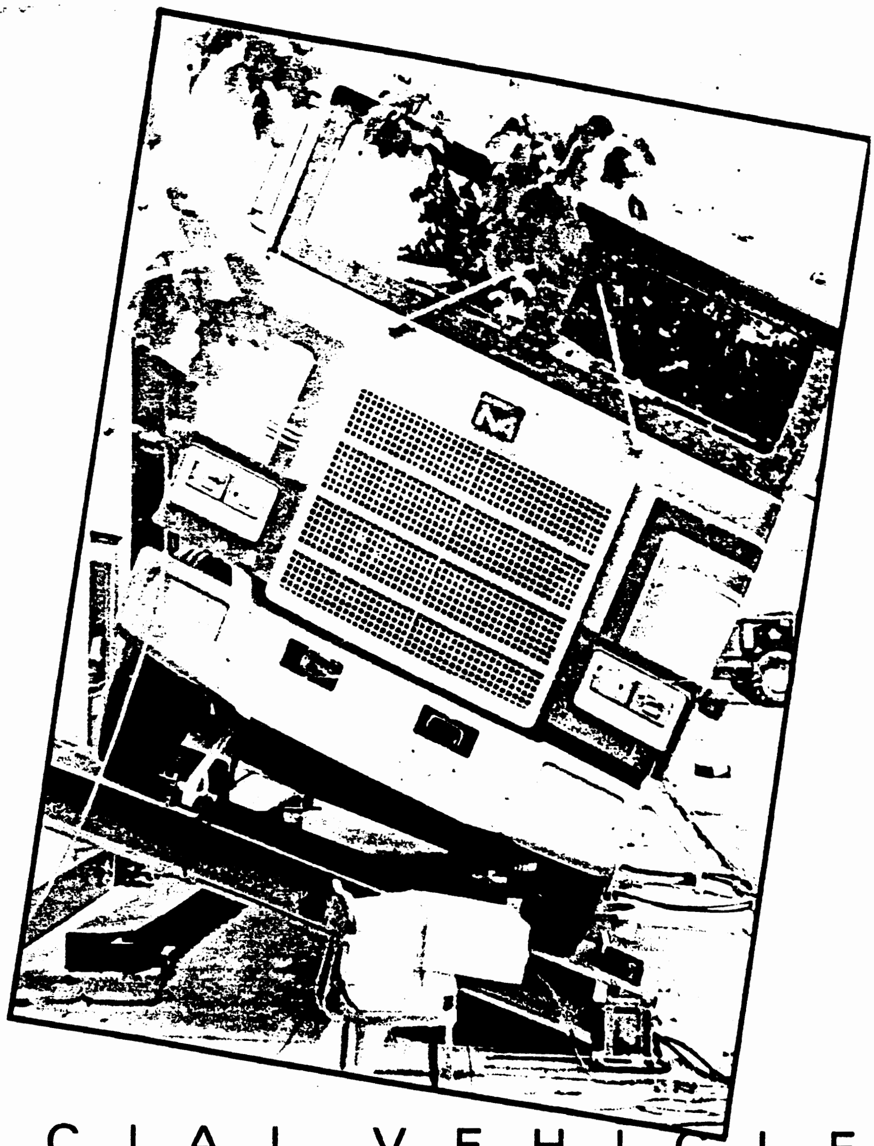
3. Ervin, R.D. *Reducing the risk of spillage in the transportation of chemical waste by truck.* Final Report No. UMTRI-88-28, University of Michigan, July, 1988.

APPENDIX

THE UNIVERSITY OF MICHIGAN Transportation Research Institute announces its

COMMERCIAL VEHICLE TILT TABLE FACILITY

for the experimental evaluation of roll stability

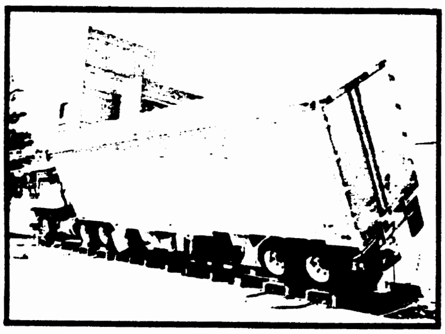


The UMTRI Tilt Table Facility uses individual "axle tilt tables" moving together under computer control. Each table unit can support an axle load of over 25,000 pounds. Five axle units currently exist, allowing tests of any vehicle configuration with up to five axles. Capability can readily be expanded by adding axle units. The UMTRI Tilt Table can simulate lateral accelerations of up to 0.5 g's.

COMMERCIAL VEHICLE TILT TABLE

THE UNIVERSITY OF MICHIGAN
TRANSPORTATION RESEARCH INSTITUTE
Engineering Research Division
2901 Baxter Road
Ann Arbor, MI 48109-2150

(313) 764-2168 or 936-1061

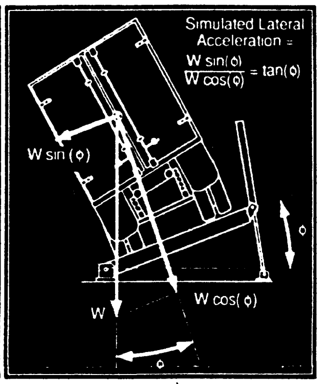


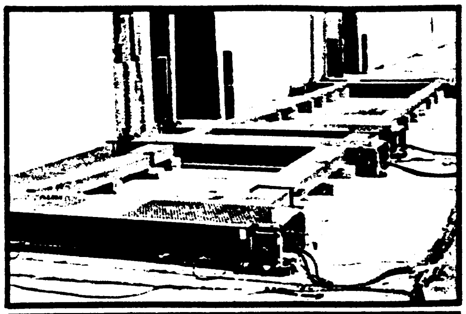
THE UNIVERSITY OF MICHIGAN TRANSPORTATION RESEARCH INSTITUTE

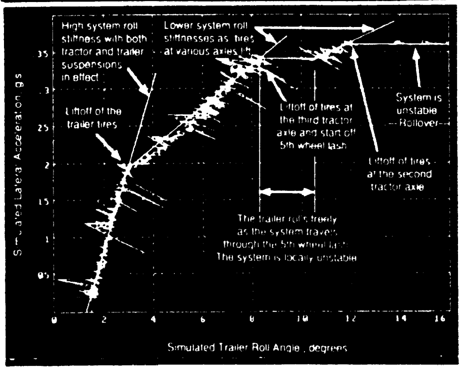
COMMERCIAL VEHICLE

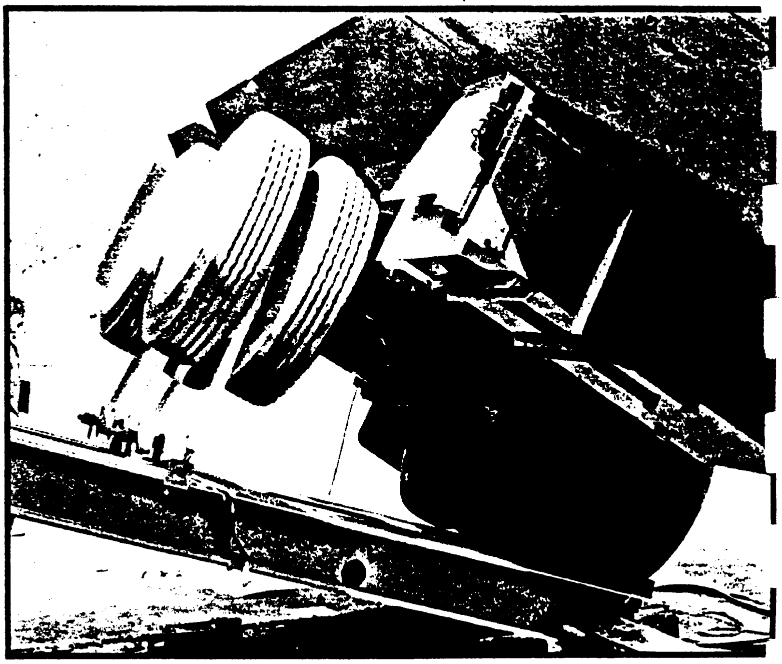
TILT TABLE

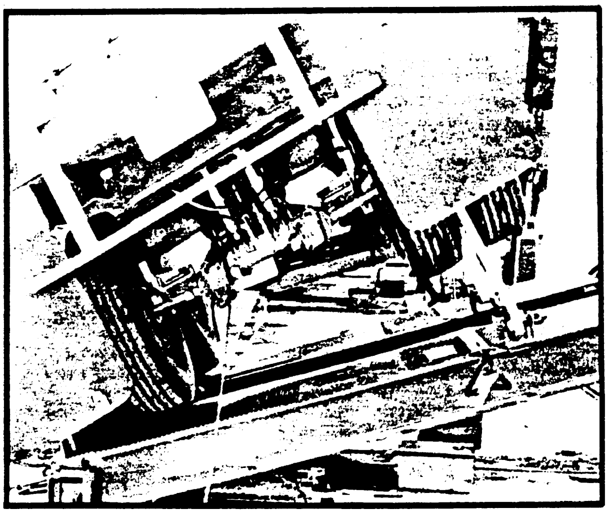
Tilt Table data is gathered using an IBM PC-based digital data acquisition system. This system provides simultaneous recording of up to 48 data signals. System software allows flexible data manipulation and presentation. Raw data, as well as data reduction software, can be made available on 5¼" floppy disks.



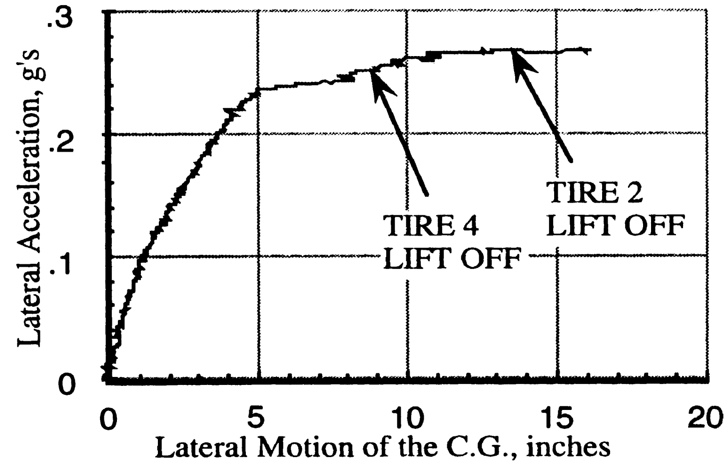




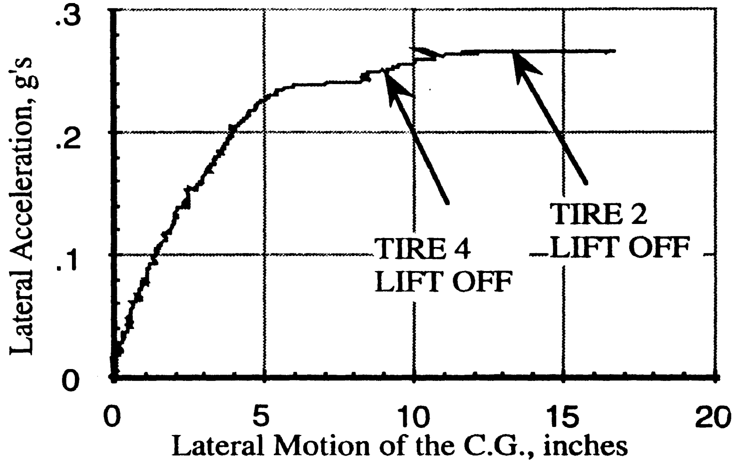




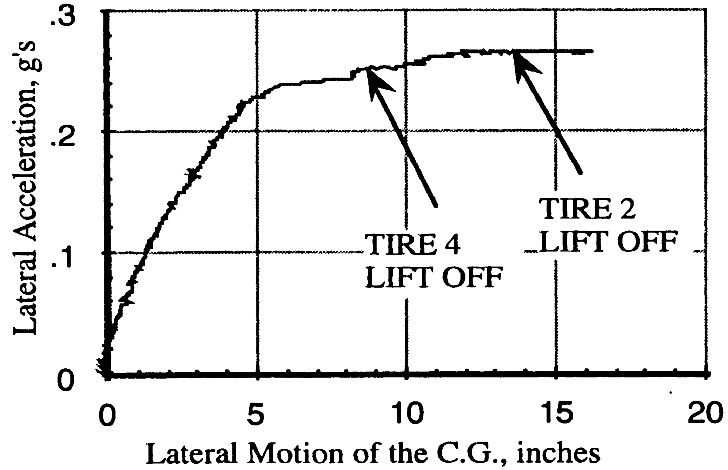
In addition to Tilt Table experiments, the UMTRI research staff conducts measurements of vehicle inertia, suspension, and tire properties, for government and industry sponsors as a supplement to its broad program of study on truck dynamic performance. If you are interested in exploring a vehicle research project or measurement service, contact Chris Winkler, (313) 936-1061.



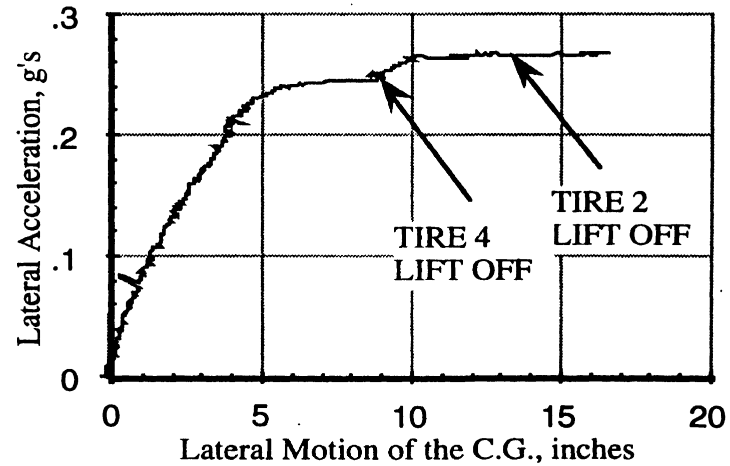
Test 1



Test2



Test 3



Test4

System stiffness plots from the four tilt table tests of the TARVAN