

INSURANCE INSTITUTE FOR HIGHWAY SAFETY

August 22, 2001

Jeffrey W. Runge, M.D.
Administrator
National Highway Traffic Safety Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

**Consumer Information Regulations; Federal Motor
Vehicle Safety Standards; Rollover Resistance
Docket No. NHTSA 2001-9663**

Dear Dr. Runge:

The Insurance Institute for Highway Safety appreciates this opportunity to comment on the National Highway Traffic Safety Administration's (NHTSA) plans to evaluate dynamic tests for rollover resistance. This is a very important research endeavor, as it has the potential to greatly improve consumer information about the large differences in rollover injury risk among passenger vehicles.

Publication of static stability factors (SSF) for new vehicles, which began earlier in 2001, has been useful in alerting consumers to differences that exist between major categories of vehicles. For example, utility vehicles and light-duty pickups generally have higher rollover injury and fatality rates than do passenger cars, and their lower SSF scores reflect that difference. However, within vehicle categories, SSF differences tend to be quite small, yet differences in real-world rollover risk can be very large. For example, among midsize utility vehicles, the Jeep Grand Cherokee and Toyota 4Runner have very similar SSFs (1.07 and 1.06, respectively), and both vehicles received only two stars in NHTSA's rollover rating system. However, real-world fatal rollover crash rates per million registered vehicles vary from 27 for the Grand Cherokee to 119 for the 4Runner. In fact, the fatal rollover rate for the Grand Cherokee is on a par with that of cars. Similarly, large real-world differences in rollover risk exist for other vehicles with equivalent SSFs, and these real-world differences are not readily explained by differences in exposure by age, sex, or rural driving (Farmer and Lund, 2000, enclosed).

SSF is an effective tool for alerting consumers to the fact that certain vehicle types have an inherently higher rollover risk, and some consumers may avoid these types as a result. However, for consumers who already have decided on a certain vehicle type, say a utility vehicle, SSF provides little guidance for their choice of vehicle, even though real-world rollover risk appears to vary greatly among these vehicles.

The goal of NHTSA's evaluation of test maneuvers should be to provide consumers with better information about the real-world differences in rollover risk among vehicles with similar SSFs. It was surprising, therefore, that the request for comments included the statement, "It is unlikely that the choice of any particular maneuver test or tests can be justified on the basis of the correlation of the test results to real-world rollover rates." This foregone conclusion is unacceptable for this research program. Any maneuver test that fails to produce such correlation, no matter how well-defined or repeatable, will provide consumers little useful information beyond the current SSF.

Because it is imperative that any dynamic test be predictive of this real-world variability, the agency should include in its test program vehicles with similar SSFs but quite different real-world fatal rollover rates. For example, the Jeep Cherokee and Jeep Grand Cherokee, which have relatively low fatal rollover rates, could be compared with the Toyota 4Runner, which has a very high fatal rollover rate. These vehicles, which have similar SSFs, are prime candidates for comparative driving maneuver tests. However, they were not included in earlier maneuver tests conducted by NHTSA, nor are they included in the proposed vehicle list for the upcoming tests. The Institute strongly recommends that the Cherokee, Grand Cherokee, and 4Runner be included in the test program. Any proposed new consumer information dynamic test should be able to distinguish the real-world rollover risk among these vehicles.

NHTSA's pessimism regarding the possibility of developing a meaningful driving maneuver test appears to derive in part from the belief that the test is meaningful only for "untripped" rollover. This sharp distinction between "tripped" and "untripped" rollovers is misleading in understanding rollover risk. Any rollover must be precipitated by some tripping force, even if it is only the force of friction between the tires and road surface. It is illogical to assume that vehicle dynamic performance that is related to untripped rollover is not also related to tripped rollover. Both driving maneuver tests and SSF measurements should yield information about the tendency of vehicles to roll when subjected to a variety of on-road and off-road conditions. The Institute therefore urges NHTSA to consider tripped as well as untripped rollover events when correlating real-world experience to driving maneuver tests of various vehicles.

We also urges NHTSA to consider factors other than wheel lift when evaluating driving maneuver tests. Other events such as early loss of control (sliding out) or tire debanding also indicate increased rollover risk. In previous agency research (Garrott et al., 1999), maneuver tests with these events were excluded from the final analyses of certain vehicles, apparently because the events were thought to lead to tripped rather than untripped rollover. However, this is one of the ways in which the arbitrary distinction between tripped and

Jeffrey W. Runge, M.D.
August 22, 2001
Page 3

untripped rollover can be misleading. In evaluating driving maneuver tests, vehicles should be scored on their ability to safely negotiate the course, not just on the basis of wheel lift. Various scoring systems should be examined and presented for public comment.

The Institute notes that NHTSA is considering a variety of path-following and open-loop steering maneuvers, as well as dynamic tests that do not involve driving maneuvers. We support this broad inclusion of possible consumer test procedures. Although some of the test maneuvers may have considerably greater consumer face validity, the ultimate decision as to which maneuvers to use should rest on which provide the best correlation with real-world rollover crash risk, as described earlier in this comment. We also concur that rollover risk cannot be evaluated adequately based solely on mathematical simulation models, and such procedures should be excluded from the agency's current efforts to expand consumer information on rollover risk.

The Institute again thanks NHTSA for this opportunity to comment on its research to identify a dynamic test procedure for evaluating rollover risk. We strongly believe that a dynamic test procedure can be developed to help consumers better understand the real-world rollover risk of different vehicle choices, including the risk of both tripped and untripped rollover. We believe just as strongly that there is little utility in additional rollover testing for consumer information unless a relationship to real-world rollover events can be identified. We look forward to the results of the agency's research.

Sincerely,

A handwritten signature in black ink, appearing to read "Adrian K. Lund".

Adrian K. Lund, Ph.D.
Chief Operating Officer

cc: Docket Clerk, Docket No. NHTSA 2001-9663

References

Farmer, C.M. and Lund, A.K. 2000. Characteristics of crashes involving motor vehicle rollover. Arlington, VA: Insurance Institute for Highway Safety.

Garrott, R.; Howe, J.G.; and Forkenbrock, G. 1999. An experimental examination of selected maneuvers that may induce on-road untripped, light vehicle rollover - phase II of NHTSA's 1997-1998 vehicle rollover research program (VRTC-86-0421). Washington, DC: National Highway Traffic Safety Administration.

**Characteristics of Crashes
Involving Motor Vehicle Rollover**

Charles M. Farmer
Adrian K. Lund

September 2000

**INSURANCE INSTITUTE
FOR HIGHWAY SAFETY**

1005 N. GLEBE RD. ARLINGTON, VA 22201-4751

PHONE 703/247-1500 FAX 703/247-1678

website <http://www.highwaysafety.org>

ABSTRACT

Characteristics of the driver, roadway environment, and vehicle were associated with the likelihood of rollover occurrence in more than 14,000 single-vehicle fatal and 78,000 single-vehicle injury crashes during 1995-98. Rollovers were more likely in crashes involving young drivers or occurring on rural curves. After accounting for the effects of driver age and gender, roadway alignment and surface condition, and whether or not the crash occurred in a rural area, light trucks were still twice as likely as cars to experience rollovers.

INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA, 1999), there were approximately 253,000 motor vehicle rollovers in 1998, of which 10,000 involved fatalities. Pickup trucks and utility vehicles, although accounting for only 28 percent of vehicles in fatal crashes as a whole, made up 41 percent of vehicles involved in fatal rollover crashes. In other words, fatal crashes of light trucks (defined here as the class of vehicles including pickups and utility vehicles) were much more likely to involve rollover than fatal crashes of cars. This overinvolvement of rollover in light truck fatal crashes has been well documented for 20 years (Flynn, 1977). However, it has taken on increased significance lately, due to the popularity of light trucks and their increasing numbers on the roads.

The static stability factor (SSF) of a vehicle, defined as one-half the track width divided by the height of the center of gravity, has been shown to be related to rollover risk (Jones and Penny, 1990; Klein, 1992; Robertson and Kelley, 1989). Once the lateral acceleration of a vehicle exceeds this ratio it is likely to roll over. Light trucks, which typically have greater ride heights than passenger cars without an offsetting increase in width, are therefore theoretically less stable. This is especially true for small utility vehicles. The SSF of the 1998 Chevrolet Tracker two-door, four-wheel-drive utility vehicle, for example, is 1.13, compared with an SSF of 1.44 for the 1998 Dodge Neon four-door car (the Neon is both wider and lower). In recognition of their lesser stability, all new utility vehicles with a wheelbase of 110 inches or less have been required since 1984 to carry a label warning drivers of increased rollover risk (49 CFR 575.105).

A vehicle stability measure related to SSF, but which also includes the effect of suspension roll stiffness, is the tilt table ratio (TTR). It is measured using a tilt table and is defined as the tangent of the smallest tilt angle that causes a vehicle's tires to break contact with the table surface. The 1998 Chevrolet Tracker and Dodge Neon have TTRs of 1.01 and 1.27, respectively.

Vehicle stability is not the only factor affecting rollover risk. The likelihood of rollover also is affected by driver behavior and roadway environment. High speed, extreme steering inputs, and roadside tripping mechanisms have all been shown to increase rollover risk (Griffin, 1981; Terhune, 1991; Viner, 1995). Even a relatively stable vehicle if sliding sideways fast can overturn. The roles of driver behavior and the environment in rollover risk are difficult to change, however. Thus making vehicles more stable may be the most effective way to reduce rollover.

The relationship between vehicle stability and rollover risk has been exhibited on the test track. As part of NHTSA's rollover research program, Garrott et al. (1999) subjected each of 12 new vehicles to five test track maneuvers intended to gauge the likelihood of untripped rollover. The first two

This work was supported by the Insurance Institute for Highway Safety.

maneuvers involved a single, sudden turn (J-turn); in one maneuver there was a brief, sharp brake application immediately into the turn. The next two maneuvers involved a sudden turn, followed immediately by a turn in the opposite direction (fishhook); steering angles and timing of the steering reversal were different for the two fishhook maneuvers. The last maneuver involved turning the steering wheel back and forth in a sinusoidal manner (resonant steer).

The first four maneuvers were repeated at progressively higher speeds until an unsafe condition was encountered or a designated maximum speed was reached (60 mph for J-turn, 50 mph for fishhook). An unsafe condition was defined as a major two-wheel lift, debanding of a tire from the wheel rim, or excessive understeer or oversteer. The resonant steer was performed nine times for each vehicle, always at 50 mph. Only three vehicles — the Dodge Neon four-door car, Dodge Caravan passenger van, and Chevrolet C1500 pickup — completed all maneuvers to the highest speed without encountering an unsafe condition. Other vehicles experienced oversteer, understeer, or tilting sufficient to briefly lift two wheels off the track. The Ford Ranger pickup, with a relatively low TTR of 0.92, experienced major two-wheel lifts during both the J-turn and fishhook maneuvers. In fact, each of the six vehicles with the lowest TTRs (and lowest SSFs) experienced some degree of two-wheel lift. On the other hand, the Dodge Caravan and Chevrolet C1500, which also have relatively low TTRs (but high SSFs), did not experience unsafe conditions in the track tests.

Despite the evidence that light trucks are less stable and roll more often than cars, there is still disagreement over how much of the rollover problem is due to vehicle instability. Motor vehicle crash rates are related to many factors besides vehicle characteristics. For example, young driver crash rates per mile driven are 4-8 times higher than crash rates for older drivers (Massie and Campbell, 1993). Thus the differences in rollover rates for various vehicle types and sizes may be partially due to differences in their popularity among young drivers. The present study examined driver, environmental, and vehicle factors believed to influence the likelihood of vehicle rollover, given that a single-vehicle crash is inevitable. In other words, what are the differences between single-vehicle crashes with and without rollover? All single-vehicle fatal crashes occurring in the United States during a 4-year period and all single-vehicle injury crashes occurring in three large states were considered. The goal was to estimate the magnitude of differences in rollover risk of cars and light trucks, after accounting for driver and environmental factors.

METHOD

Information on all single-vehicle fatal crashes of passenger vehicles in the United States during 1995-98 was extracted from the Fatality Analysis Reporting System (FARS), an electronic database of

fatal crashes occurring on public roadways. Vehicle registration counts by state, calendar year, model year, and vehicle model were obtained from the National Vehicle Population Profile of The Polk Company. Information on all single-vehicle crashes in Florida, Pennsylvania, and Texas during 1995-98 that involved at least one injured party (including fatalities) was extracted from the State Data System maintained by the National Center for Statistics and Analysis (NCSA). The State Data System is made up of police-reported crash data submitted annually by 17 states and modified by NCSA to a common file structure (NHTSA, 1997).

Minimum property damage criteria for reporting crashes vary by state, but in all states crashes involving personal injury must be reported to police. Crashes in Florida, Pennsylvania, and Texas were therefore restricted to those involving personal injury, so as to allow for unbiased comparisons across states. This restriction, however, could introduce a bias into comparisons of rollover rates among vehicles. A vehicle that is especially protective of occupants during a rollover may have a lower injury rollover rate than a vehicle that is not so protective, even if the first vehicle is more likely to roll. This study could not address this issue.

Single-vehicle crashes were defined as those involving only one motor vehicle. Thus crashes of passenger vehicles into other (including parked) motor vehicles were excluded. For each single-vehicle crash, the information extracted consisted of year of crash, location of crash (rural, urban), light condition (darkness, daylight), road surface condition (slippery, dry), roadway alignment (curved, straight), driver gender (male, female), driver age (younger than 25, 25 or older), vehicle type (car, passenger van, light truck), and vehicle make, model, and model year.

Older vehicles may be driven in different circumstances and by a vastly different driver population than newer vehicles. Extreme differences in vehicle age could confound comparisons of vehicles. Among vehicles involved in single-vehicle fatal crashes in 1997, 16 percent of pickups were more than 15 years old, whereas only 9 percent of cars in the database were that old. Fatal rollover rates per registered vehicle per year were computed separately for vehicles between 1 and 3 years old and for those vehicles more than 3 years old, providing further evidence of a vehicle age effect. Therefore, all subsequent analyses were restricted to vehicles between 1 and 3 years old.

For cases in FARS and in Florida and Pennsylvania, vehicle make, model, and model year were derived from the vehicle identification number (VIN) included in most records. The electronic file in Texas does not include VINs, so vehicle information was derived from the make, model, and model year codes of the Texas Department of Public Safety. Interestingly, VINs are recorded on the original Texas police reports and can be used to check the accuracy of the make-model codes. In a comparison of Texas make-model codes to makes and models derived from VINs of passenger cars on 1,000 randomly

sampled police reports, more than 86 percent were in agreement. The Texas make-model codes for light trucks, however, often are too general for specific model identification. For example, nearly half the Ford pickups in the Texas database were coded only as “Ford Truck.” Therefore, there was no attempt made in this study to define subclasses of Texas light trucks.

For each of the databases, passenger cars, including passenger vans, were classified into five size groups according to both wheelbase and overall length. Pickups and utility vehicles were classified into four groups according to weight (except in Texas). Rollover rates per registered vehicle per year were calculated for each vehicle type and size category. In addition, rollover rates were computed for each of 40 top-selling models of cars and light trucks.

The rollover rates discussed above provide a comparison of rollover fatality and injury risk among the various vehicle classifications, as these vehicles are driven. They do not control for potential differences among the vehicles in terms of driver population or driving conditions (Donelson et al., 1999). To examine the rollover risk while controlling for these factors, a different rollover risk metric is necessary because the rollover injury rate per registered vehicle cannot be calculated for the subpopulations (vehicle registration data cannot be subdivided according to driver age or principal driving condition). Therefore, the effects of driver age, roadway alignment, and urban/rural location were accounted for by separating single-vehicle fatal crashes into categories according to these driver and environmental factors, as well as vehicle type and size, and then computing the percentage of each category that were rollovers. Finally, logistic regression analyses were used to statistically compare the percentages of rollovers among all single-vehicle fatal/injury crashes for the various environmental, driver, and vehicle characteristics in the data.

RESULTS

Table 1 lists fatal rollover rates per million registered vehicles per year for each vehicle type and for vehicles between 1 and 3 years old compared with vehicles more than 3 years old. The rollover rate for newer cars is the same as that for older cars, but newer utility vehicles are noticeably less likely than their predecessors to be involved in fatal rollovers. This is likely due to the fact that newer utility vehicles tend to be larger than their predecessors, and several utility vehicle models notorious for their high rollover rates were retired from production prior to 1992 (Zador et al., 1992).

Table 2 lists fatal rollover rates per million registered vehicles per year for the five size classes of cars, four size classes of pickups, and four size classes of utility vehicles. This analysis and all that follow were restricted to vehicles between 1 and 3 years old. Overall, pickups and utility vehicles were more than twice as likely as cars to be involved in fatal rollovers. Within vehicle types, large vehicles

were less likely than smaller vehicles to be involved in fatal rollovers. However, even the heaviest pickups had fatal rollover rates higher than those for mini cars, and only the heaviest utility vehicles had fatal rollover rates as low as small cars.

Table 1
Single-Vehicle Fatal Rollover Crashes in the United States, 1995-98
All Passenger Vehicles

Vehicle Type and Age	Single-Vehicle Fatal Rollovers	Registered Vehicle-Years	Rollover Rate per 1,000,000 Registration-Years
Cars and Passenger Vans			
1-3 yr.	3,218	110,453,668	29
>3 yr.	11,232	377,514,435	30
Pickups			
1-3 yr.	1,640	27,991,042	59
>3 yr.	5,338	96,521,267	55
Utility Vehicles			
1-3 yr.	1,259	18,162,664	69
>3 yr.	2,893	31,520,002	92
All Passenger Vehicles			
1-3 yr.	6,266	160,417,305	39
>3 yr.	20,200	523,345,054	39

Table 2
Single-Vehicle Fatal Rollover Crashes in the United States, 1995-98
1-3-Year-Old Passenger Vehicles

Vehicle Type and Size	Single-Vehicle Fatal Rollovers	Registered Vehicle-Years	Rollover Rate per 1,000,000 Registration-Years
Cars and Passenger Vans			
Mini	185	3,991,440	46
Small	952	26,739,109	36
Midsize	1,445	44,483,509	32
Large	560	30,200,353	19
Very large	66	5,039,257	13
All cars and passenger vans*	3,218	110,453,668	29
Pickups			
Light (<3,000 lb.)	463	5,835,444	79
Midweight (3,000-3,999 lb.)	639	11,061,138	58
Heavy (4,000-4,999 lb.)	455	9,583,150	47
Very heavy (>4,999 lb.)	78	1,511,310	52
All pickups*	1,640	27,991,042	59
Utility Vehicles			
Light (<3,000 lb.)	197	1,913,305	103
Midweight (3,000-3,999 lb.)	655	9,370,772	70
Heavy (4,000-4,999 lb.)	330	5,501,763	60
Very heavy (>4,999 lb.)	54	1,376,824	39
All utility vehicles*	1,259	18,162,664	69
All Passenger Vehicles	6,266	160,417,305	39

*Rollover total includes vehicles of undetermined size

Tables 3, 4, and 5 list the injury rollover rates per million registered vehicles per year for Florida, Pennsylvania, and Texas, respectively. Patterns are similar to those in Table 2. Light trucks had much higher rollover rates than cars. Also, within vehicle types, smaller vehicles were more likely than larger vehicles to be involved in rollovers. It is evident, however, that injury rollover rates for the three states differ greatly from each other. The overall passenger vehicle injury rollover rate in Texas was twice that of Florida, with Pennsylvania approximately halfway in between.

Table 3
Single-Vehicle Injury Rollover Crashes in Florida, 1995-98
1-3-Year-Old Passenger Vehicles

Vehicle Type and Size	Single-Vehicle Injury Rollovers	Registered Vehicle-Years	Rollover Rate per 1,000,000 Registration-Years
Cars and Passenger Vans			
Mini	145	321,677	451
Small	703	2,042,774	344
Midsize	621	3,015,680	206
Large	236	1,965,441	120
Very large	34	524,727	65
All cars and passenger vans*	2,017	7,870,299	256
Pickups			
Light (<3,000 lb.)	443	510,615	868
Midweight (3,000-3,999 lb.)	332	633,810	524
Heavy (4,000-4,999 lb.)	121	341,808	354
Very heavy (>4,999 lb.)	14	46,229	303
All pickups*	911	1,532,462	594
Utility Vehicles			
Light (<3,000 lb.)	174	174,653	996
Midweight (3,000-3,999 lb.)	614	681,064	902
Heavy (4,000-4,999 lb.)	83	178,553	465
Very heavy (>4,999 lb.)	10	32,669	306
All utility vehicles*	881	1,066,939	826
All Passenger Vehicles	4,023	10,731,754	375

*Rollover total includes vehicles of undetermined size

Table 6 gives a comparison of fatal rollover rates for 40 specific vehicle models, which were either among the top-selling models in each vehicle type/size class or one of the 12 models subjected to NHTSA's track tests (Garrott et al., 1999). For each model, rollovers and registrations were summed over a set of model years with no differences in either vehicle design or occupant restraints. Each model had at least 80,000 registration-years of exposure nationwide during 1995-98. Again, within vehicle types, smaller vehicles generally were more likely to be involved in rollovers than larger vehicles, and light trucks were more likely to roll over than cars. However, there were some exceptions; the Chevrolet Lumina four-door car and Chevrolet Astro passenger van had fatal rollover rates much higher than those of other large cars and passenger vans. The Jeep Cherokee and Grand Cherokee utility vehicles had fatal rollover rates much

lower than those of other utility vehicles of similar size. Four-wheel-drive pickups had fatal rollover rates much higher than their two-wheel-drive versions. Just the opposite was true for utility vehicles; four-wheel-drive utility vehicles had fatal rollover rates lower than their two-wheel-drive versions.

Table 4
Single-Vehicle Injury Rollover Crashes in Pennsylvania, 1995-98
1-3-Year-Old Passenger Vehicles

Vehicle Type and Size	Single-Vehicle Injury Rollovers	Registered Vehicle-Years	Rollover Rate per 1,000,000 Registration-Years
Cars and Passenger Vans			
Mini	160	167,258	957
Small	771	1,257,743	613
Midsize	943	2,268,470	416
Large	357	1,495,956	239
Very large	20	182,020	110
All cars and passenger vans*	2,303	5,371,447	429
Pickups			
Light (<3,000 lb.)	97	109,506	886
Midweight (3,000-3,999 lb.)	335	363,959	920
Heavy (4,000-4,999 lb.)	199	387,818	513
Very heavy (>4,999 lb.)	19	41,810	454
All pickups*	670	903,093	742
Utility Vehicles			
Light (<3,000 lb.)	232	117,223	1,979
Midweight (3,000-3,999 lb.)	460	465,650	988
Heavy (4,000-4,999 lb.)	318	318,174	1,000
Very heavy (>4,999 lb.)	17	54,645	311
All utility vehicles*	1,053	955,692	1,102
All Passenger Vehicles	4,102	7,399,426	554

*Rollover total includes vehicles of undetermined size

Table 5
Single-Vehicle Injury Rollover Crashes in Texas, 1995-98
1-3-Year-Old Passenger Vehicles

Vehicle Type and Size	Single-Vehicle Injury Rollovers	Registered Vehicle-Years	Rollover Rate per 1,000,000 Registration-Years
Cars and Passenger Vans			
Mini	278	233,352	1,191
Small	1,562	1,722,813	907
Midsize	1,854	2,989,740	620
Large	608	1,838,360	331
Very large	40	430,669	93
All cars and passenger vans*	4,577	7,214,934	634
Light Trucks**	5,107	4,471,500	1,142
All Passenger Vehicles	9,747	11,941,205	816

*Rollover total includes vehicles of undetermined size

**Pickups and utility vehicles could not be distinguished in many cases

Table 6
Single-Vehicle Fatal Rollover Crashes per Million Registration-Years, 1995-98
1-3-Year-Old Selected Passenger Vehicles

Vehicle Type and Size	Vehicle Make and Model	Model Years	SSF	TTR	Rollover Rate
Cars and Passenger Vans					
Mini	Toyota Tercel two-door	1995-97	1.39	n/a	53
Mini	Chevrolet Metro/Suzuki Swift two-door*	1995-97	1.29	1.13	42
Small	Ford Escort/Mercury Tracer four-door	1995-96	1.38	n/a	42
Small	Dodge Neon/Plymouth Neon four-door*	1995-97	1.44	1.27	37
Small	Nissan Sentra four-door	1995-97	1.40	n/a	30
Small	Honda Civic two-door	1996-97	1.43	n/a	26
Small	Saturn SL four-door	1995-97	1.35	n/a	22
Midsized	Toyota Camry four-door	1994-96	1.46	n/a	18
Midsized	Honda Accord four-door	1994-97	n/a	n/a	15
Large	Chevrolet Lumina four-door*	1995-97	1.34	1.12	32
Large	Ford Taurus/Mercury Sable four-door	1996-97	n/a	n/a	15
Large	Chevrolet Astro/GMC Safari 2WD passenger van*	1995-97	1.12	0.97	36
Large	Ford Windstar 2WD passenger van	1995-97	1.24	n/a	14
Large	Dodge Caravan/Plymouth Voyager/Chrysler Town & Country 2WD passenger van*	1996-97	1.24	1.02	12
Very large	Ford Crown Victoria/Mercury Grand Marquis four-door	1994-97	1.42	n/a	14
Very large	Lincoln Town Car four-door	1994-97	1.44	n/a	13
2WD Pickups					
Light	Chevrolet S10/GMC S15/Isuzu Hombre*	1995-97	1.14	1.05	86
Light	Ford Ranger/Mazda B series	1995-97	1.11	n/a	69
Midweight	Chevrolet/GMC 1500 series*	1995-96	1.22	1.07	46
Midweight	Ford F-150 series	1994-96	1.19	n/a	37
Heavy	Dodge Ram 1500 series	1995-97	1.22	n/a	48
4WD Pickups					
Midweight	Chevrolet S10/GMC S15	1995-97	1.14	n/a	101
Midweight	Ford Ranger/Mazda B series*	1995-97	1.07	0.92	87
Heavy	Chevrolet/GMC 1500 series	1995-96	1.14	n/a	66
Heavy	Ford F-150 series	1994-96	1.15	n/a	44
Heavy	Dodge Ram 1500 series	1995-97	n/a	n/a	60
2WD Utility Vehicles					
Light	Chevrolet Tracker/Suzuki Sidekick two-door	1994-95	n/a	n/a	196
Light	Jeep Cherokee four-door	1995-96	n/a	n/a	37
Midweight	Honda Passport/Isuzu Rodeo four-door	1996-97	n/a	n/a	150
Midweight	Toyota 4Runner four-door	1996-97	n/a	n/a	80
Midweight	Jeep Grand Cherokee four-door	1996-97	n/a	n/a	66
Heavy	Ford Explorer four-door	1995-97	1.06	n/a	84
Very heavy	Chevrolet Tahoe/GMC Yukon four-door	1995-96	n/a	n/a	23
4WD Utility Vehicles					
Light	Chevrolet Tracker/Suzuki Sidekick two-door*	1994-95	1.13	1.01	127
Midweight	Jeep Cherokee four-door	1995-96	1.08	1.01	12
Midweight	Honda Passport/Isuzu Rodeo four-door	1996-97	1.06	0.93	104
Midweight	Toyota 4Runner four-door	1996-97	1.06	n/a	119
Midweight	Jeep Grand Cherokee four-door	1996-97	1.07	n/a	27
Heavy	Ford Explorer four-door*	1995-97	1.06	0.90	51
Very heavy	Chevrolet Tahoe/GMC Yukon four-door*	1995-96	1.12	0.97	40

2WD=two-wheel drive, 4WD=four-wheel drive

Note: SSF and TTR are taken from NHTSA (2000) and the NHTSA Vehicle Inertial Parameter Measurement Database available at <http://www-nrd.nhtsa.dot.gov/vrtc/ca/rollover.htm>

*Included in the track tests of Garrott et al. (1999)

Table 6 also includes the SSF and TTR, if available, for each vehicle. All cars and passenger vans in the table, with the exception of the Chevrolet Astro, had SSFs higher than 1.20. Utility vehicles, on the other hand, had SSFs no higher than 1.13. The cars in the table also had generally higher TTRs than the utility vehicles, but the passenger vans had low TTRs.

Injury rollover rates in Florida, Pennsylvania, and Texas for the 40 specific vehicle models are listed in Table 7. Rates in individual states often were imprecise due to low exposure, but patterns in injury rollover rates for the three states combined were consistent with those of the fatal rollover rates. Just as with fatal rollover rates, the Chevrolet Lumina and Chevrolet Astro had higher injury rollover rates than like vehicles. The Jeep Cherokee and Grand Cherokee had unusually low injury rollover rates. However, the Ford Ranger, which had a lower fatal rollover rate than the Chevrolet S10, had a much higher injury rollover rate.

The simultaneous effects on rollover risk of driver, environmental, and vehicle factors can be studied either through logistic regression analyses or by comparing the percentages of rollovers among various subgroups of crashes. Table 8 lists the percentages of rollovers among crashes classified by driver age, crash location, roadway alignment, vehicle size, and vehicle type. Rollover risk was highest on rural curves, but even urban curves were risky for young drivers of the smaller light trucks. Sixty-eight percent of the single-vehicle fatal crashes of young drivers in smaller light trucks on urban curves were rollovers.

Table 9 lists the ratios of the odds of rollover among contrasting categories of crashes produced by logistic regression. For example, the odds of rollover in a fatal rural crash were more than 3 times as high as in a fatal urban crash (odds ratio=3.42). For injury crashes, the odds of rollover in a rural crash also were more than 3 times that of an urban crash. Other results that were consistent across the fatality data and the three state injury files were the effects of roadway alignment, driver age, vehicle size, and vehicle type. The odds of rollover in a crash were higher on curves than on straight roads, higher for drivers younger than 25 than for drivers 25 or older, higher for small vehicles than for large vehicles, and higher for light trucks than for cars and passenger vans.

Among fatal crashes nationwide and injury crashes in Texas, single-vehicle crashes involving male drivers were less likely to be rollovers than crashes involving female drivers. So, although male drivers may be more likely than female drivers to be involved in single-vehicle crashes, their single-vehicle crashes are less likely to involve rollover. Driver gender had no significant effect on rollover odds in Florida and Pennsylvania.

Table 7
Single-Vehicle Injury Rollover Crashes per Million Registration-Years, 1995-98
1-3-Year-Old Selected Passenger Vehicles

		Rollover Rate per 1,000,000 Registration-Years			
Vehicle Type and Size	Vehicle Make and Model	Florida	Pennsylvania	Texas	Total
Cars and Passenger Vans					
Mini	Toyota Tercel two-door	243	*	982	491
Mini	Chevrolet Metro/Suzuki Swift two-door	432	1,231	1,382	954
Small	Ford Escort/Mercury Tracer four-door	581	838	1,766	1,076
Small	Dodge Neon/Plymouth Neon four-door	240	601	958	609
Small	Nissan Sentra four-door	369	308	1,024	605
Small	Honda Civic two-door	396	477	665	497
Small	Saturn SL four-door	309	388	593	420
Midsize	Toyota Camry four-door	162	265	361	252
Midsize	Honda Accord four-door	89	194	294	188
Large	Chevrolet Lumina four-door	236	397	603	426
Large	Ford Taurus/Mercury Sable four-door	157	280	397	284
Large	Chevrolet Astro/GMC Safari 2WD passenger van	256	*	627	437
Large	Ford Windstar 2WD passenger van	117	201	278	200
Large	Dodge Caravan/Plymouth Voyager/ Chrysler Town & Country 2WD passenger van	60	163	204	138
Very large	Ford Crown Victoria/Mercury Grand Marquis four-door	59	109	133	93
Very large	Lincoln Town Car four-door	58	75	35	51
2WD Pickups					
Light	Chevrolet S10/GMC S15/Isuzu Hombre	731	707	n/a	726
Light	Ford Ranger/Mazda B series	996	1,260	n/a	1,040
Midweight	Chevrolet/GMC 1500 series	348	466	n/a	368
Midweight	Ford F-150 series	371	327	n/a	361
Heavy	Dodge Ram 1500 series	379	*	n/a	334
4WD Pickups					
Midweight	Chevrolet S10/GMC S15	*	1,073	n/a	1,000
Midweight	Ford Ranger/Mazda B series	*	2,144	n/a	2,121
Heavy	Chevrolet/GMC 1500 series	479	368	n/a	407
Heavy	Ford F-150 series	595	542	n/a	553
Heavy	Dodge Ram 1500 series	613	598	n/a	602
2WD Utility Vehicles					
Light	Chevrolet Tracker/Suzuki Sidekick two-door	1,779	*	n/a	1,933
Light	Jeep Cherokee four-door	794	*	n/a	786
Midweight	Honda Passport/Isuzu Rodeo four-door	1,297	*	n/a	1,288
Midweight	Toyota 4Runner four-door	1,188	*	n/a	1,182
Midweight	Jeep Grand Cherokee four-door	444	*	n/a	442
Heavy	Ford Explorer four-door	1,068	*	n/a	1,062
Very heavy	Chevrolet Tahoe/GMC Yukon four-door	*	*	n/a	*
4WD Utility Vehicles					
Light	Chevrolet Tracker/Suzuki Sidekick two-door	*	3,014	n/a	2,949
Midweight	Jeep Cherokee four-door	*	939	n/a	876
Midweight	Honda Passport/Isuzu Rodeo four-door	*	*	n/a	*
Midweight	Toyota 4Runner four-door	*	*	n/a	967
Midweight	Jeep Grand Cherokee four-door	351	449	n/a	427
Heavy	Ford Explorer four-door	745	1,084	n/a	1,026
Very heavy	Chevrolet Tahoe/GMC Yukon four-door	*	164	n/a	142

2WD=two-wheel drive, 4WD=four-wheel drive

Note: Specific models of pickups and utility vehicles could not be adequately distinguished in the Texas database

*Fewer than 10,000 registration-years of exposure, so rates are unreliable

Table 8
Percentage of Rollovers Among Single-Vehicle Fatal Crashes, 1995-98
1-3-Year-Old Passenger Vehicles

Covariate	Mini/Small/ Midsize Car	Large/ Very Large Car	Light/ Midweight Light Truck	Heavy/ Very Heavy Light Truck
Urban, straight road (N=4,407)				
Driver <25 yr.	20.3	28.2	32.4	28.6
Driver ≥25 yr.	15.5	10.8	21.0	15.6
Urban, curved road (N=1,220)				
Driver <25 yr.	41.0	45.5	68.5	57.1
Driver ≥25 yr.	38.7	29.5	51.9	50.0
Rural, straight road (N=5,641)				
Driver <25 yr.	50.4	53.5	62.5	63.1
Driver ≥25 yr.	41.7	40.0	54.9	55.3
Rural, curved road (N=3,143)				
Driver <25 yr.	57.2	60.3	70.2	70.9
Driver ≥25 yr.	57.4	56.6	71.7	68.3

Note: 398 single-vehicle fatal crashes were excluded due to missing values on one or more covariates

Table 9
Ratio of Rollover Odds Among Single-Vehicle Fatal/Injury Crashes, 1995-98
1-3-Year-Old Passenger Vehicles

Covariate	FARS (N=14,411)	Florida (N=22,853)	Pennsylvania (N=15,506)	Texas (N=39,748)
Location of Crash				
Rural vs. urban	3.42	3.02	2.89	3.88
Light Condition				
Darkness vs. daylight	0.89	1.20	1.19	0.91
Road Surface Condition				
Slippery vs. dry	0.69	1.32	1.19	0.79
Roadway Alignment				
Curved vs. straight	2.15	2.19	1.47	1.42
Driver Gender				
Male vs. female	0.86	0.93*	1.02*	0.92
Driver Age				
<25 yr. vs. ≥25 yr.	1.36	1.59	1.39	1.28
Vehicle Size				
Mini/small/midsize/light/midweight vs. larger/heavier	1.04*	1.15	1.06*	n/a
Vehicle Type				
Light truck vs. car/passenger van	1.78	2.61	2.13	1.89

*Odds ratio not significantly different from 1.00

The effects of darkness and wet roads differed across the four data sets. For fatal crashes nationwide and injury crashes in Texas, rollover odds were lower in darkness than in daylight and lower on slippery roads than on dry roads. For injury crashes in Florida and Pennsylvania, rollover odds were higher in darkness than in daylight and higher on slippery roads than on dry roads.

The logistic regression analysis also was used to predict the likelihood of rollover for each single-vehicle fatal crash based on the driver, environmental, and vehicle factors listed in Table 9. Averaging these values for all crashes involving a particular vehicle model yields an expected likelihood of rollover for that vehicle model. For each of the 40 specific vehicle models in this study, actual and expected percentages of rollovers among single-vehicle fatal crashes are listed in Table 10.

Unusually high (or low) expected percentages of rollovers are indications that a vehicle's unusually high (or low) rollover rate is due to some factor, such as driver age, included in the logistic regression model. However, the expected percentages were pretty consistent within vehicle type and size categories. For example, based on the characteristics of its single-vehicle fatal crashes, the Chevrolet Astro was expected to have had 32 percent rollovers, similar to the Ford Windstar and Dodge Caravan. The fact that the Chevrolet Astro actually had 51 percent rollovers means that there are factors affecting the rollover risk of this vehicle that we have not accounted for in this study.

DISCUSSION

Rollover rates for light trucks per registration per year were more than twice those of passenger cars. This was true not only for fatal crashes nationwide but also for injury crashes in each of three distinctly different states. In Florida, a relatively flat coastal state, light trucks accounted for 45 percent of single-vehicle injury rollovers but only 24 percent of passenger vehicle registrations. Similarly in Pennsylvania, a somewhat mountainous northern state, light trucks accounted for 42 percent of single-vehicle injury rollovers but only 25 percent of passenger vehicle registrations. In Texas, a very large, highly rural western state, light trucks accounted for 52 percent of single-vehicle injury rollovers but only 37 percent of passenger vehicle registrations.

Larger vehicles tended to roll over less often than smaller vehicles of the same type, but specific vehicle comparisons point out the need for more information. For example, the fatal rollover rate for the large Chevrolet Astro passenger van during 1995-98 was approximately the same as that of the small Dodge Neon four-door car. The Astro is 18 inches longer, 10 inches wider, and 1,700 pounds heavier than the Neon. However, the Astro's center of gravity is 29 inches off the ground, 9 inches higher than the Neon's. The SSFs of the Astro and Neon are 1.12 and 1.44, respectively. The TTRs of the Astro and Neon are 0.97 and 1.27, respectively. Stability is also affected by the weight distribution of occupants and cargo, so a fully-loaded Astro would be even more unstable (Whitfield and Jones, 1995).

Light truck injury and fatal crashes involved rollover more often than car crashes, and this was true for a variety of crash circumstances (Table 8). Whether on urban roads, rural roads, straight sections, or curves, light trucks overturned more often than cars. Light truck rollovers with injury or

Table 10
Single-Vehicle Fatal Crashes, 1995-98
1-3-Year-Old Selected Passenger Vehicles

Vehicle Type and Size	Vehicle Make and Model	Single-Vehicle Fatal Crashes	Actual Percentage of Rollovers	Expected Percentage of Rollovers
Cars and Passenger Vans				
Mini	Toyota Tercel two-door	35	43	36
Mini	Chevrolet Metro/Suzuki Swift two-door*	32	31	38
Small	Ford Escort/Mercury Tracer four-door	70	34	37
Small	Dodge Neon/Plymouth Neon four-door*	131	39	40
Small	Nissan Sentra four-door	60	32	40
Small	Honda Civic two-door	19	42	35
Small	Saturn SL four-door	60	40	35
Midsized	Toyota Camry four-door	116	35	35
Midsized	Honda Accord four-door	134	27	36
Large	Chevrolet Lumina four-door*	89	48	41
Large	Ford Taurus/Mercury Sable four-door	71	28	33
Large	Chevrolet Astro/GMC Safari 2WD passenger van*	35	51	32
Large	Ford Windstar 2WD passenger van	60	32	32
Large	Dodge Caravan/Plymouth Voyager/Chrysler Town & Country 2WD passenger van*	52	37	33
Very large	Ford Crown Victoria/Mercury Grand Marquis four-door	109	24	33
Very large	Lincoln Town Car four-door	49	24	30
2WD Pickups				
Light	Chevrolet S10/GMC S15/Isuzu Hombre*	205	56	45
Light	Ford Ranger/Mazda B series	179	52	42
Midweight	Chevrolet/GMC 1500 series*	157	38	43
Midweight	Ford F-150 series	188	38	41
Heavy	Dodge Ram 1500 series	68	50	41
4WD Pickups				
Midweight	Chevrolet S10/GMC S15	35	54	57
Midweight	Ford Ranger/Mazda B series*	33	55	55
Heavy	Chevrolet/GMC 1500 series	138	49	56
Heavy	Ford F-150 series	101	44	53
Heavy	Dodge Ram 1500 series	50	56	48
2WD Utility Vehicles				
Light	Chevrolet Tracker/Suzuki Sidekick two-door	34	65	60
Light	Jeep Cherokee four-door	23	30	60
Midweight	Honda Passport/Isuzu Rodeo four-door	18	72	61
Midweight	Toyota 4Runner four-door	15	47	54
Midweight	Jeep Grand Cherokee four-door	15	60	61
Heavy	Ford Explorer four-door	59	73	67
Very heavy	Chevrolet Tahoe/GMC Yukon four-door	5	40	50
4WD Utility Vehicles				
Light	Chevrolet Tracker/Suzuki Sidekick two-door*	36	61	69
Midweight	Jeep Cherokee four-door	15	40	56
Midweight	Honda Passport/Isuzu Rodeo four-door	13	77	62
Midweight	Toyota 4Runner four-door	24	75	56
Midweight	Jeep Grand Cherokee four-door	26	62	61
Heavy	Ford Explorer four-door*	90	63	62
Very heavy	Chevrolet Tahoe/GMC Yukon four-door*	26	54	58

2WD=two-wheel drive, 4WD=four-wheel drive

Note: Expected percentage of rollovers based on the logistic regression summarized in Table 9

*Included in the track tests of Garrott et al. (1999)

fatality were most common among young drivers, but even older drivers were more likely to be involved in rollovers when driving light trucks.

Results of the logistic regressions, although differing in some details, are clear and consistent on one main point. After taking into account differences in drivers and roadway environments, a light truck is approximately twice as likely as a car to roll over in a single-vehicle crash. Furthermore, this increased risk is not confined to small utility vehicles but extends to larger pickups and utility vehicles. All the evidence, then, points to the same conclusion: Light trucks are both theoretically and manifestly more prone to roll over than cars. What is left to decide, then, is at what point the risk of rollover becomes unreasonable. Are there some light trucks that are so unstable they should not be allowed on the road, and how can they be identified?

A recent report by NHTSA (2000) contains a mathematical formula relating SSF to the risk of vehicle rollover in a single-vehicle crash, after accounting for differences in driver and environmental factors. The formula is based on a statistical analysis of the crash experience of 100 vehicle models over 4 years in six states. The formula is statistically biased, however, because the environmental factors accounted for in the analysis did not include whether the crash occurred on a rural road. It is to be expected that light trucks would be at higher risk of rollover than cars simply because they have greater exposure to rural roads. All vehicles in the study with low SSFs were light trucks, and all those with high SSFs were cars. It is not surprising, then, that the low SSF vehicles were involved in more rollovers than the high SSF vehicles. This confounding of SSF with roadway environment precludes an accurate examination of the relationship between this measure of vehicle stability and rollover risk, although the laws of physics dictate it must be positive.

NHTSA is proposing to use SSF values to provide consumers with information on rollover risks for new vehicles. As noted above, physics indicates that SSF and stability must be related. However, there continues to be controversy about the relative importance of vehicle parameters versus driver and environmental factors and the extent to which SSF identifies meaningful differences within a class of vehicles. It is clear that both SSF and TTR identify large differences in rollover risks among different vehicle classes, but there are substantial variations in fatal rollover crash rates for some individual models that are not consistent with these static measurements. For example, the four-wheel-drive Jeep Grand Cherokee had a very low single-vehicle fatal rollover rate (27) (Table 6), whereas the four-wheel-drive Toyota 4Runner had a very high rate (119) (Table 6). Yet the SSF values for these vehicles are almost the same (1.07 compared with 1.06). Furthermore, the smaller four-wheel-drive Chevrolet Tracker/Suzuki Sidekick, which has a higher SSF than either the Grand Cherokee or the 4Runner, had a single-vehicle fatal rollover rate (127) higher than that of the 4Runner (Table 6).

Static stability measures such as SSF and TTR are unlikely to be as good indicators of rollover propensity as well-designed dynamic tests. For example, the vehicles that performed worst in the J-turn or fishhook tests run by Garrott et al. (1999), the Chevrolet Tracker and Ford Ranger, had the highest fatal and injury rollover rates of any vehicles tested (Tables 6-7). Although vehicle handling tests may be sensitive to subtle variations in driver inputs and environmental conditions, they are inexpensive to replicate and can therefore be repeated until statistically reliable results are achieved. Dynamic track testing then, subject to tightly defined conditions and sufficiently replicated, seems the best option ultimately for distinguishing differences in rollover risk related to vehicle designs.

REFERENCES

- Donelson, A.C.; Ramachandran, K.; Zhao, K.; and Kalinowski, A. 1999. Rates of occupant deaths in vehicle rollover: importance of fatality-risk factors. *Transportation Research Record* 1665:109-17. Washington, DC: Transportation Research Board.
- Flynn, L. 1977. Rollover accidents: a subject bibliography from highway safety literature (DOT HS-802-875). Washington, DC: National Highway Traffic Safety Administration.
- Garrott, R.; Howe, J.G.; and Forkenbrock, G. 1999. An experimental examination of selected maneuvers that may induce on-road untripped, light vehicle rollover – phase II of NHTSA’s 1997-1998 vehicle rollover research program (VRTC-86-0421). Washington, DC: National Highway Traffic Safety Administration.
- Griffin, L.I. 1981. Probability of overturn in single vehicle accidents as a function of road type and passenger car curb weight (TARE-44). College Station, TX: Texas Transportation Institute.
- Jones, I.S. and Penny, M.B. 1990. Engineering parameters related to rollover frequency. SAE Technical Paper Series 900104. Warrendale, PA: Society of Automotive Engineers.
- Klein, T.M. 1992. A statistical analysis of vehicle rollover propensity and vehicle stability. SAE Technical Paper Series 920584. Warrendale, PA: Society of Automotive Engineers.
- Massie, D.L. and Campbell, K.L. 1993. Analysis of accident rates by age, gender, and time of day based on the 1990 Nationwide Personal Transportation Survey. Ann Arbor, MI: University of Michigan Transportation Research Institute.
- National Highway Traffic Safety Administration. 1997. State Data System: a summary of motor vehicle traffic crashes from state crash data files (DOT HS-808-626). Washington, DC: U.S. Department of Transportation.
- National Highway Traffic Safety Administration. 1999. Traffic safety facts 1998. Washington, DC: U.S. Department of Transportation.
- National Highway Traffic Safety Administration. 2000. Consumer information regulations; federal motor vehicle safety standards; rollover prevention (NHTSA Docket 2000-6859). Washington, DC: U.S. Department of Transportation.
- Robertson, L.S. and Kelley, B.A. 1989. Static stability as a predictor of overturn in fatal motor vehicle crashes. *The Journal of Trauma* 29:313-19.
- Terhune, K.W. 1991. The contribution of rollover to single-vehicle crash injuries (report no. 7881-1). Buffalo, NY: Arvin/Calspan Transportation Sciences Center.
- Viner, J.G. 1995. Risk of rollover in ran-off-road crashes. *Transportation Research Record* 1500:112-18. Washington, DC: Transportation Research Board.
- Whitfield, R.A. and Jones, I.S. 1995. The effect of passenger load on unstable vehicles in fatal, untripped rollover crashes. *American Journal of Public Health* 85:1268-71.
- Zador, P.L.; Williams, A.F.; and Ciccone, M.A. 1992. Fatal rollover rates of small utility vehicles and pickups. Arlington, VA: Insurance Institute for Highway Safety.