THE ROLE OF STABILITY IN ROLLOVER-INITIATED FATAL MOTOR-VEHICLE CRASHES UNDER ON-ROAD DRIVING CONDITIONS

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Abstract

Fatal Accident Reporting System (FARS) files for the years 1981-84 were examined for rollover-initiated, on-road fatal crash involvement records of fifteen utility and passenger vehicle make-models for which stability values (1/2 track width divided by height of center of gravity) were known. The values ranged from highs of 1.57-1.62 for the pre-1979 full-sized Ford, the pre-1979 Chevrolet Nova and the pre-1982 Pontiac Firebird to lows of 1.01-1.10 for the Jeep CJ-5 and CJ-7 and the pre-1978 Ford Bronco. The CJ-5 and CJ-7 were treated as a single make-model for purposes of the study.

The rollover-initiated fatal crashes per 100,000 vehicles registered were compared for each involved make-model, using data from R. L. Polk Co. Such crashes as a percentage of all fatal crashes for the involved make-models were plotted in relation to their vehicle stability values. The persistence of the correlations found between such crashes as a percentage of all fatal crashes and the stability values was tested by introduction of other road, driver and environmental risk factors recorded in the FARS files, using multiple regression analysis.

Using Federal Highway Administration vehicle mileage estimates, calculations were made of the mileages under various conditions which the vehicles with low stability values would have to have been driven if mileage or hazardous-condition differences rather than stability differences accounted for their substantially higher rollover-initiated fatal crash rates.

The following findings were reached:

1. Vehicles of the make-models with the lowest stability values--the CJs and the pre-1978 Broncos--had rollover-initiated fatal crash rates many times greater than those for the other make-models. Both the CJs and pre-1978 Bronco had rates greater than 16 per 100,000 registered vehicles, compared with rates ranging from 0.6 to 4.7 for any other make-model, or a three to sixteen-fold difference.

However, for fatal single-vehicle crashes with no initial rollover and for fatal multiple-vehicle crashes with no initial rollover, these same vehicles had rates within the ranges found for the other vehicles.

2. The differences between the make-models in rollover-initiated fatal crashes as a percentage of all fatal crashes strongly correlated with the stability values for the compared make-models. The lowest stability values were associated with the highest crash rates. About 65 percent of the variation in percent rollovers was explained by variation in stability.

3. Introduction of other major risk factors in the analysis of stability values relative to percent rollovers failed to negate this outcome. Factors introduced included rural vs. urban environment, interstate vs. other roads, speed limits at crash sites, time of day, road alignment and gradation, road surface type and condition, validity of driver's license, prior license suspension, blood alcohol concentration of fatally injured drivers, previous drunk-driving convictions, previous violation or crash records, or sex and age of drivers.

4. The mileage calculations revealed that for the excess in fatal crashes resulting from rollovers of CJs and pre-1978 Broncos to be explained by mileage or hazardous driving differences from the other make-models, the CJs and pre-1978 Broncos would have to have been driven an average mileage per year far greater than could be reasonably expected. For instance, male drivers of CJs would have to have driven them an average of about 123,000 miles each year if mileage differences were to account for their excess rollover-induced fatal crashes of those vehicles.

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Introduction

In "On-Road Crash Experience of Utility Vehicles" (Snyder et al., 1980), the on-road collision experience of various utility vehicles "designed for on/off road use" was examined so as to "determine the nature, extent and seriousness of any problems unique to this category of vehicle..."

On the basis of their examination of data from a range of primary and secondary sources, the researchers concluded that the percentage share of rollover crashes appeared to be much higher for "Jeep" vehicles and pre-1978 Ford Broncos than for both other utility vehicles and passenger automobiles.

The researchers also ranked five utility vehicles by their stability values (1/2 track width divided by height of center of gravity) and compared them to seven passenger vehicles for which such values were available. They found the CJ vehicles (CJ-5 and CJ-7, manufactured by Jeep Corporation, a subsidiary of American Motors Corporation, or "AMC") to have the lowest stability values of the vehicles considered, but only slightly lower than the pre-1978 Broncos manufactured by Ford Motor Company. As a group, these vehicles had stability values substantially less than those of the passenger cars. They concluded that the lower the stability value, the greater the likelihood of rollover "as an on-road (tire traction force-induced) phenomenon," all other factors being equal.

In a series of 500 tests of the stability of six passenger vehicles and 1 truck (neither CJs nor Broncos were included), in ten configurations on test tracks, Rice et al. (1978) drew the same conclusion (p. 17): "There can be no question that vehicle rollover resistance is dependent on the rigid body geometry parameter - e.g. height to half-tread ratio - to first order."

In "A Comparison of the Crash Experience of Utility Vehicles, Pickup Trucks and Passenger Cars" (Reinfurt et al., 1981), the researchers compared three utility vehicles--the CJ-5, the Ford Bronco and the Chevrolet Blazer--with selected pickup trucks and with passenger car groups for their overall crash experience in two states, as well as their national fatal-crash experience as recorded by the Fatal Accident Reporting System of the National Highway Traffic Safety Administration.

They found that the CJ-5 had substantially higher single-vehicle (but not multi-vehicle) crash involvement rates than the other studied vehicles, and that when involved in single-vehicle crashes, the CJ-5 had the highest percentage of rollovers of the vehicles studied. Examination of rollover percentages by driver age groups for the studied utility vehicles in the two states "suggests that age is not an important factor for any particular utility vehicle model involved in rollover crashes," they concluded.

In "A Further Look at Utility Vehicle Rollovers" (Reinfurt et al., 1984), the researchers examined North Carolina crash-report data for the same vehicles and vehicle groups as in "Comparison," and in addition looked at the CJ-7 and the International Scout utility vehicles.

They found that both the CJ-5 and CJ-7 had substantially higher single-vehicle (but not multi-vehicle) crash rates than the other studied vehicles, and substantially higher single-vehicle rollover rates. They also concluded that driver age, vehicle mileage, driver sex, intoxication, speed and driver violation records failed to account for the differences in rates. A more detailed review of these studies is available (Kelley, 1985).

Joksch (1983) argued that utility vehicles had greater crash involvement because of mileage accumulated under unusual conditions or by atypical drivers. However, he failed to separate rollover crashes by driving conditions or drivers and, therefore, did not address the issue of excess rollovers in relation to those factors.

In the present study we have examined and compared the rates of involvement in rollover-initiated fatal crashes of three utility vehicle make-models--the CJ (CJ-5 and CJ-7 are treated as a single make-model), the pre-1978 Ford Bronco and the Chevrolet Blazer--and eleven automobile make-models.

We also have looked at the role of vehicle stability values as a factor in explaining differences in those rates and the roles, if any, of other risk-related variables. Finally, we have tested the assumption that the higher rollover crash rates reported for CJs and pre-1978 Broncos is attributable to their being driven more miles than other vehicles, or being driven under more hazardous conditions.

Method

In contract with the state governments, the National Highway Traffic Safety Administration obtains data on each fatal incident involving a motor vehicle in the U.S. The data in this Fatal Accident Reporting System (FARS) include road and weather conditions, federally-required vehicle identification numbers encoding vehicle characteristics, and characteristics of drivers coded according to uniform specifications.

To examine the involvement of selected vehicles in rollover fatalities, including road, vehicle and driver data, the computer tapes containing the FARS data for the calendar years 1981 through 1984 were examined. The vehicles to be studied were selected on two bases -- availability of published measurements of center of gravity and use in sufficient numbers for statistical analysis. Snyder, et al. (1980) and Rice, et al. (1978) indicate center of gravity measurement for the vehicles in Table 1. The vehicles are ranked from least to most stable according to the physical formula T/2/H.

Rice, et al., (1978) obtained somewhat different measurements of center of gravity on separate Pintos. The center of gravity measured by Snyder, et al. (1980) was near the median of the Pintos measured by Rice, et al. (1978) and was used in the analysis.

Where indicated, more recent model years were excluded because vehicles were redesigned with different dimensions than those models with the same names in the model year that center of

Table 1. Track (T), Height of Center of Gravity (H) and Theoretical Stability of Vehicles (T/2/H) Selected Because of Published Center of Gravity and Use in Sufficient Numbers for Statistical Analysis.

Vehicle	T	Snyder, et al. CG	Snyder, et al. T/2/H	Rice, et al. CG	Rice, et al. T/2/H
Jeep CJ5	60.15	26.45	1.01		
Jeep CJ7	53.25	24.80	1.07		
Pre-1978 Ford Bronco	60.00	27.19	1.10		
Chevrolet Blazer	65.75	27.14	1.21		
Pre-1973 Dodge Coronet	60.85			24.0	1.27
Pre-1979 Olds Toronado	63.60	24.00	1.32		
Ford Pinto	55.00	20.60	1.33	19.5	1.41
				22.1	1.24
AMC Gremlin	57.50			21.5	1.34
Volkswagen Beetle	52.45	19.38	1.35		
Pre-1983 AMC Concord	59.00	21.10	1.40		
Pre-1981 AMC Pacer	60.60	21.38	1.42		
Pre-1974 Ford Mustang	58.50	19.80	1.47		
Pre-1979 Full-Sized Ford	64.30	20.50	1.57		
Pre-1979 Chevrolet Nova	60.15	19.03	1.58		
Pre-1982 Pontiac Firebird	61.05	18.79	1.62		

rollovers as a percent of all fatal crashes in relation to T/2/H was examined for a wide variety of environmental, road and driver characteristics known to be related to fatal crash involvement. This coefficient is simply the increase (if positive) or decrease (if negative) in number of percentage points in rollover relative to other fatal crashes per unit change in T/2/H. The purpose of this analysis was to examine the coefficients and variance explained under a variety of conditions. If the regression coefficient for T/2/H remained relatively large even with the introduction of coefficients for other major risk factors, those other factors could not account for the major variation in rollover crashes among vehicles, assuming reasonably similar mileage among vehicles driven under the specified conditions.

Third, the argument that utility vehicle mileage is accumulated under conditions or by drivers so different from passenger cars as to explain the different rollover rates was examined in terms of what that mileage would have to be to produce the differences observed. Estimates produced annually by the Federal Highway Administration (1982-1985) measuring mileage by rural versus urban and type of road (interstate versus others), were available. Also, a 1977 survey was available of mileage by age and sex of driver and by age of car (Federal Highway Administration, 1979; National Highway Traffic Safety Administration, 1977). If the higher rollovers per vehicle observed in this and previous studies were a function of driving under more hazardous conditions or by more hazardous drivers, the ratio of miles driven by utility vehicles to miles driven by passenger cars under those conditions should equal the ratio of rollovers of utility vehicles per number of vehicles to rollovers of passenger vehicles per number of vehicles.

Therefore, the miles necessary to produce the rollover rate of utility vehicles under given conditions could be calculated from the formula:

$$\frac{\text{Utility Veh. Roll/Vehicle}}{\text{Passenger Veh. Roll/Vehicle}} = \frac{\text{Utility Veh. Miles/Vehicle}}{\text{Passenger Veh. Miles/Vehicle}}$$

If the utility vehicle miles per vehicle necessary to generate the relative rollover rates under given hazardous conditions were within reason, then rollover could simply be a function of excess mileage or mileage accumulated under hazardous conditions. Implausible mileage estimates would indicate that these conditions are not the explanation of excess fatal crashes due to rollovers.

Results

Vehicles of the make-models indicated in Table 1 were involved in 12,465 crashes where one or more occupants died during 1981-84. Of these, 1,343 (11 percent) were rollover-initiated.

The rollover-initiated fatal crash rates per 100,000 vehicles per year for each of the vehicles studied are presented in Figure 1. As found in previous studies, the pre-1978 Broncos and Jeep CJs had rollover rates per vehicle several times greater than did a variety of passenger cars and the Blazer, also a utility vehicle. The pre-1978 Bronco and CJ rates were greater than 16 per 100,000 vehicles per year compared to car and Blazer rates that ranged from 0.6 to 4.7. The rollover-initiated crashes were

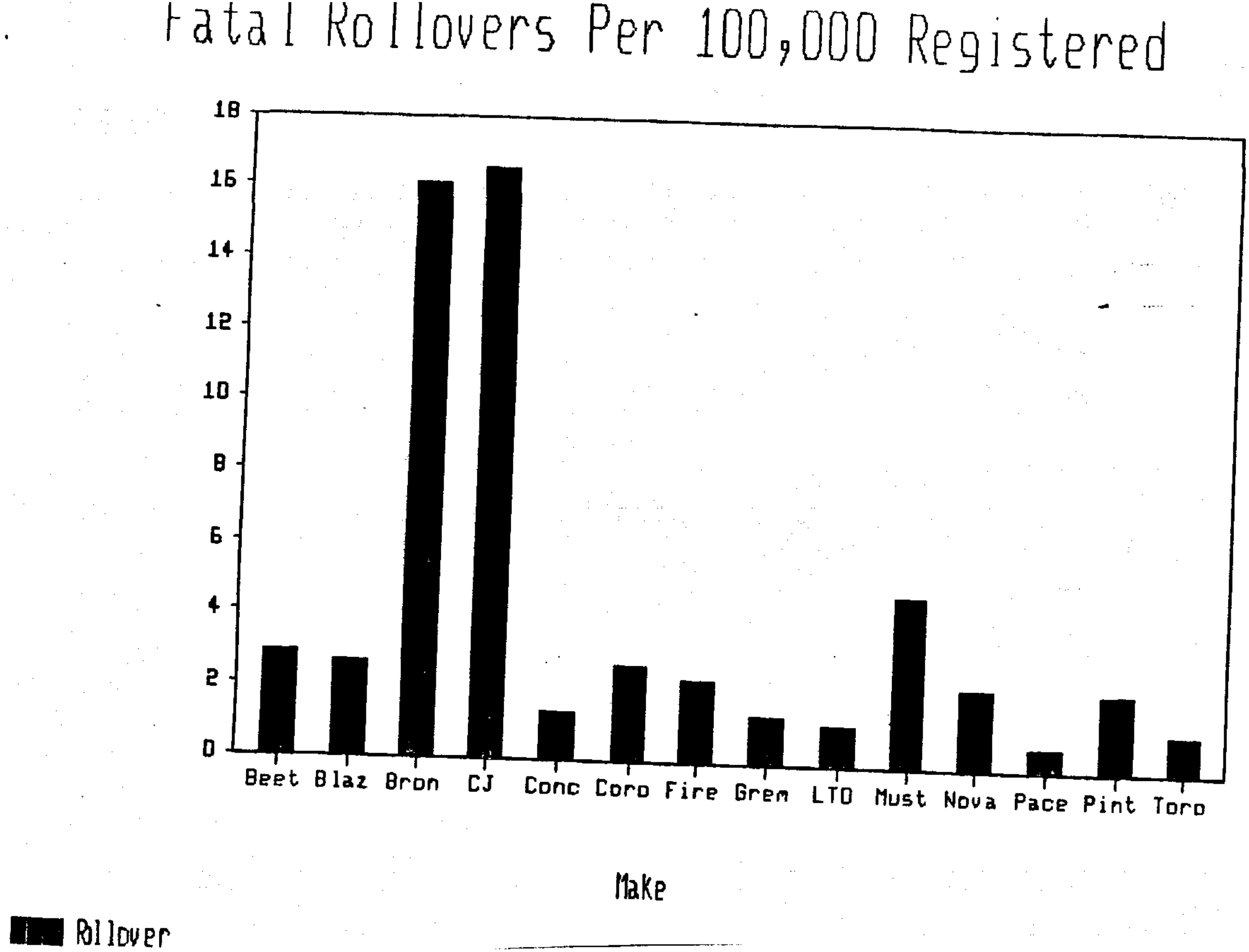
Fatal Rollovers Per 100,000 Registered
18
16
14
12
10
8
6
4
2
0
Beet Blaz Bron CJ Conc Coro Fire Grem LTD Must Nova Pace Pint Toro
Make
Rollover

FIGURE 1

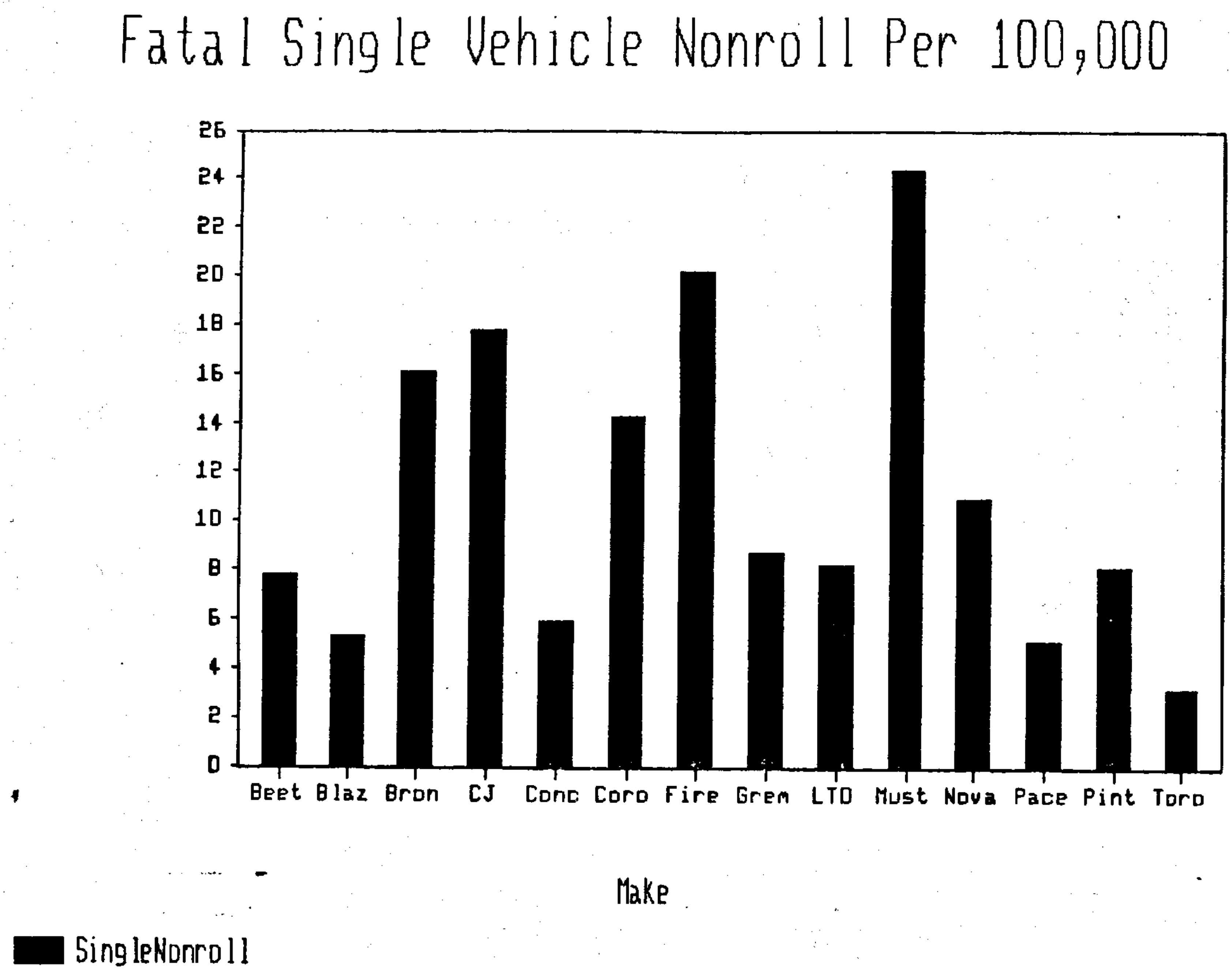
Fatal Single Vehicle Nonroll Per 100,000
26
24
22
20
18
16
14
12
10
8
6
4
2
0
Beet Blaz Bron CJ Conc Coro Fire Grem LTD Must Nova Pace Pint Toro
Make
SingleNonroll

FIGURE 2

predominately single vehicle; only 14 of 6061 multiple-vehicle crashes were rollover-initiated.

The rates of fatal single-vehicle crashes that did not involve rollovers are shown in Figure 2. For these types of crashes, the rates for Jeep CJs and pre-1978 Broncos were within the range of those seen for other vehicles. Also, as revealed by the fatal multiple-vehicle rates charted in Figure 3, the rates for these two utility vehicles were again within the range seen for other vehicles.

Therefore, the excess fatal crashes per registered vehicle observed in the Jeep CJs and the pre-1978 Broncos were the result of rollovers. By excess fatal crashes or excess fatalities, we mean those crashes that would not have occurred had the pre-1978 Broncos and Jeep CJs had rollover rates similar to the other vehicles.

In the following analysis, the percent of all fatal crashes that were rollovers is examined in relation to the stability formula, T/2/H, of the vehicle, where T equals the width in inches between wheels and H equals the height in inches of the center of gravity.

In the regression equation:

$$\text{Percent roll} = a + b\ (\text{stability}) + e.$$

In the formula b is the best fitting slope of a line fitted through the scatter of the plotted data. The point at which the line crosses the vertical axis when stability is 0 is indicated in the equation by a and the variation not explained by stability is indicated by e. Figure 4 presents a plot of the percent rollover as a function of stability along with a and b from the

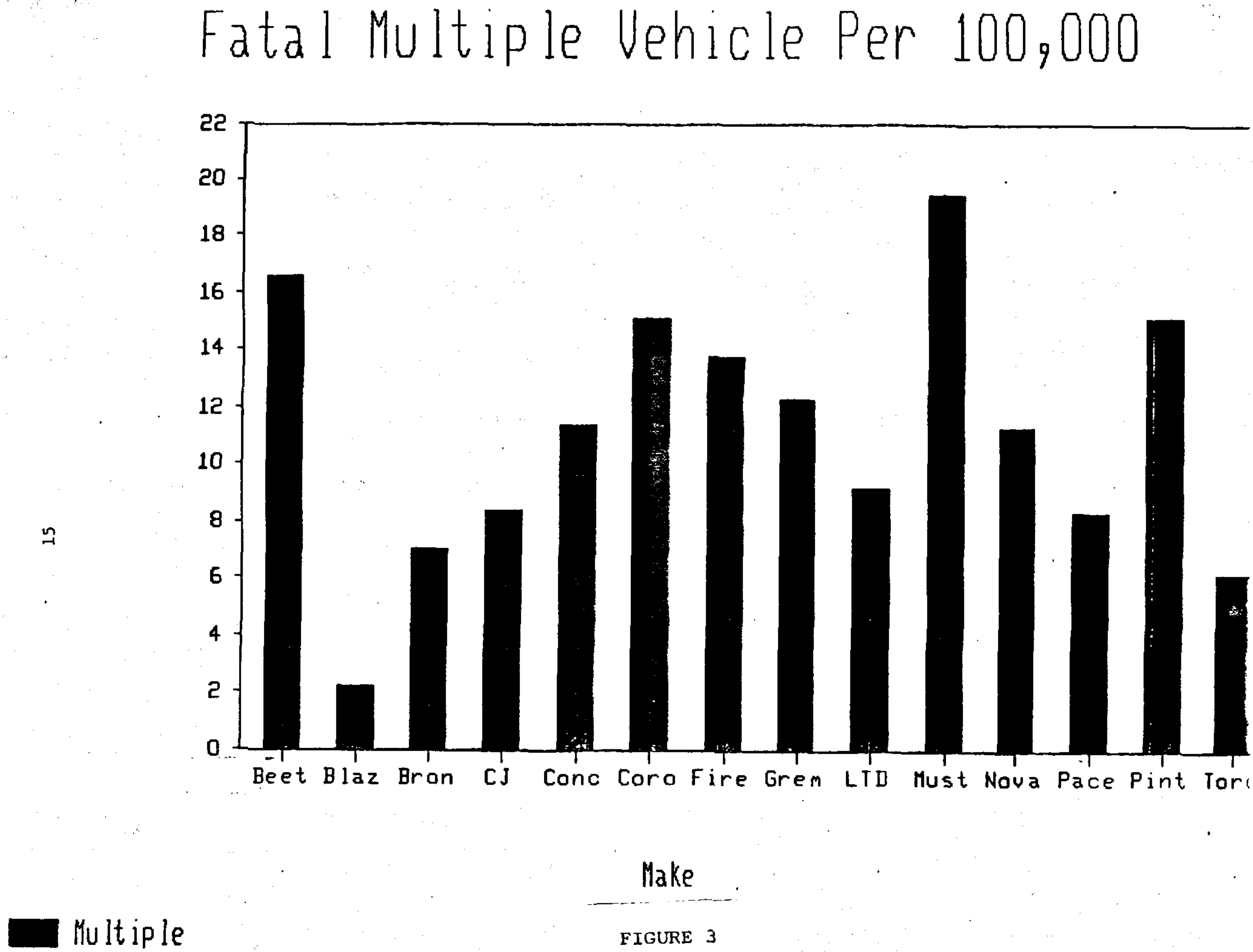
Fatal Multiple Vehicle Per 100,000
22
20
18
16
14
12
10
8
6
4
2
0
Beet
Blaz
Bron
CJ
Conc
Coro
Fire
Grem
LTD
Must
Nova
Pace
Pint
Tor
Make
Multiple

FIGURE 3

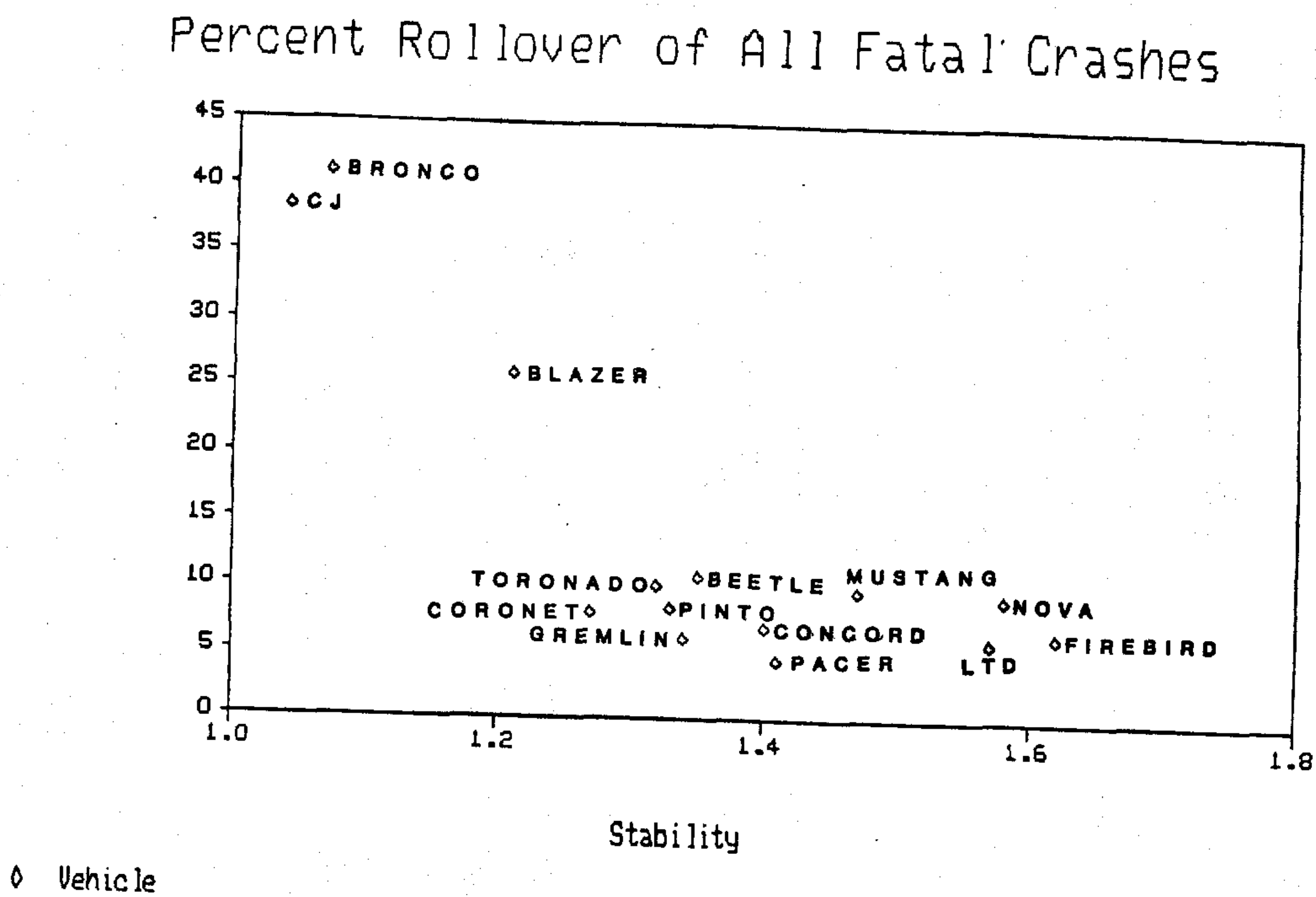

FIGURE 4

Percent Rollover = 90.5 - 56.7(T/2/H)

Percent variance explained = 65

regression equation and an indication of variance explained. The variance explained is the ratio of the variation due to the regression line to the total variation multiplied by 100. If all of the data points were on the regression line, the variance explained would be 100 percent. If the percent rollover were randomly scattered relative to stability, the regression coefficient and the variance explained would be zero.

In this case, almost two-thirds (65%) of the variation in percent rollovers among the vehicles was explained by stability. The model was also tested using the logarithm of the percent rollover with no improvement in variance explained. Therefore, percent rollover is a linear function of vehicle stability.

A summary of the regression analyses of percent of all fatal crashes that were initiated by rollover introducing the major known risk factors for fatal crashes is presented in Table 2. They are described below:

Environment and Roads. The studied vehicles were generally involved in fatal rollovers proportionately less in urban than in rural areas. The regression coefficient indicated an average of 10.4 percentage points greater rollovers in rural areas. The coefficient for stability, -46.2, was not quite as strongly negative as in the original equation, but nevertheless remains very large.

The vehicles with low stability had high rollover rates relative to those with higher stability on all types of roads -- interstates, other U.S. highways, state and local roads. The coefficient for interstates, the safest roads, versus the others was small and not statistically significant.

Table 2. Regression Analyses of Percent Rollover-Initiated Fatal Crashes of All Fatal Crashes By Vehicle Stability (T/2/H) and Major Risk Factors For Fatal Crashes

	Risk Factor Coefficient	t	Stability Coefficient	t	% Variance Explained
Environment					
Rural vs. Urban	10.4	3.7	-46.2	-5.5	64
Interstate vs. other	2.2	0.7	-50.7	-5.9	58
55 mph vs. other	6.3	2.2	-55.1	-6.4	65
Daylight vs. other	2.0	0.7	-56.7	-6.5	63
Curve vs. straight	8.3	2.9	-58.3	-6.9	69
Grade vs. level	2.0	0.7	-55.8	-6.8	65
Off vs. On-road	9.9	3.2	-59.0	-6.5	68
Blacktop vs. concrete	4.3	1.6	-46.1	-5.8	59
Wet vs. dry	-2.4	-0.8	-59.1	-6.6	64
Two-lane vs. four+	9.3	3.6	-45.2	-5.9	66
Driver					
Valid licence vs. other	-2.4	-0.8	-62.4	-6.6	64
Prior suspension	1.5	0.5	-56.2	-6.7	65
BAC present	3.8	0.9	-63.9	-5.2	53
Illegal BAC	3.9	1.0	-62.7	-5.2	53
Prior DWI conviction	5.9	1.8	-59.4	-6.2	63
Prior speed conviction	2.8	0.9	-58.9	-6.1	60
Prior other conviction	-0.1	-0.0	-57.0	-6.1	60
Prior crash	-2.2	-0.8	-53.8	-6.2	61
Men vs. women	0.1	0.0	-61.4	-6.7	64
25 or older vs. younger	-3.7	-1.3	-56.5	-6.9	66

Where t is greater than 2.15 or less than -2.15, the coefficient is statistically significant at $p<0.05$ (two-tailed test); otherwise the coefficient is likely the result of chance fluctuation.

Given the lack of difference among roads, it is not surprising that posted speed limit also made little difference, an average of about 6 percentage points. The strong correlation of stability and percent rollover was found both on roads with a 55 mph limit and on roads with lower limits.

The presence or absence of daylight had little effect on the correlation of stability and percent rollover. The coefficient for daylight versus night, dawn or dusk was not large enough to be statistically significant.

The alignment of the road was related to rollover, as might be suspected from the greater lateral force on curves. The average percent rollover for all the studied vehicles was about 8 percentage points higher on curved road sections. Nevertheless, there was a substantially higher rollover percentage among the low stability vehicles on both straight and curved road sections.

Road gradient had less effect than curvature. The coefficient for graded sections was not statistically significant.

Rollover was proportionately greater relative to nonrollover crashes, by an average 10 percentage points, if the vehicle left the road beyond the median or shoulder. Nevertheless, the low stability vehicles had high proportionate rollover on the road as well as off.

The type of road surface -- blacktop vs. concrete -- made no significant difference. Data for other road surfaces (slag, dirt, etc.) were not included in this factor because the numbers per vehicle were too small for stable percentaging. Only 3 percent of fatal crashes of the vehicles studied occurred on roads with surfaces other than blacktop and concrete.

A wet surface made little difference in the percent of rollovers. The coefficient for wet versus dry surface was not statistically significant. Other road surface conditions were not included in this analysis because only 4 percent of the fatal crashes studied occurred where there was snow, ice or sand on the road -- too few for analysis by vehicles involved.

Rollover occurred proportionately more often on two-laned roads compared to those with four or more lanes, an average difference of about 9 percentage points. The strong association of rollover and low stability remained on both types of roads. The one and three-lane roads were not included in this analysis because they accounted for only 3 percent of the fatal crashes studied.

Drivers. The percent rollovers of all fatal crashes in relation to stability differed little for drivers with valid licenses and for those with no license, invalid licenses and learners permits. The effect of having a valid license was not statistically significant. The correlation of stability and rollover was strong in both groupings of drivers.

Having had a license suspended previously was also uncorrelated to percent rollovers of all fatal crashes. The percent rollovers declined sharply as stability increases and previous suspension had no statistically significant effect.

Claims have been made that alcohol is used more often by drivers of utility vehicles based on police impressions of alcohol use (Joksch, 1983). It has long been well documented that such police judgments in the absence of objective chemical tests are often incorrect (e.g, Haddon and Bradess, 1959). Also, such judgments are confined to whether or not alcohol was present, and not to the amount. This is particularly true for the severely or fatally injured in crashes, where there are no behavioral manifestations of intoxication.

To reduce the possible bias of judgment in ascertaining alcohol, including bias of medical examiners and coroners in selecting cases for testing, the data from fifteen states that chemically test 80 percent or more of fatally injured drivers for blood alcohol concentration (BAC) were separated from the total study population. Only those cases in which the driver died were included because, even in these states, the majority of drivers who survive a crash in which someone else died are not tested for alcohol.

The presence of alcohol made only about a 4 percentage point difference in percent rollovers as indicated by the coefficient of 3.8, and is not statistically significant. The percent rollovers of fatally injured drivers in Jeep CJs was substantially higher for those with no detectable alcohol in blood than for those with detectable alcohol. More than two-thirds of the fatally injured CJ drivers without alcohol were in rollovers compared to about 40 percent of those with detectable alcohol. On average, the correlation of percent rollover and stability was strong with or without alcohol.

The alcohol factor was also examined in terms of whether an amount illegal in most states (0.10% or higher by weight) was found in the fatally injured drivers. The result was virtually the same as the analysis for any alcohol. Percent rollover was much higher in the low stability vehicles whether for drivers with illegal blood alcohol or for those within legal limits.

Returning to the total study population, we examined percent rollover in relation to stability for drivers who had, and those who did not have previous convictions for driving while intoxicated (DWI). In both groupings, the correlation of stability and percent rollover remained strong and a prior DWI conviction had no statistically significant effect.

Previous convictions for speeding were not significantly related to percent rollover. There was less than a 3 percentage point difference, on average, in rollover percent between those with prior speeding convictions and those without.

Convictions for violations other than DWI and speeding had no effect on the results. The coefficient for "other convictions" was near zero. A driver record of one or more previous police-reported crashes also had little relation to percent rollovers. The coefficient was not statistically significant and the relationship between stability and percent rollover remained sharply negative.

The difference between male and female drivers in percent rollovers of all fatal crashes by vehicle stability showed no effect. The average difference between the sexes was nil.

The final driver factor, age of driver, was not a statistically significant factor. Drivers 25 and older had an average of about 4 percentage points less in percent rollovers of all fatal crashes than younger drivers across the various levels of stability. Most of the variation in percent vehicle rollovers again was explained by stability.

In sum, none of the variables -- whether environmental, road or driver -- that are known to be related to overall risk of fatal crashes, explained the differences between the studied vehicles in proportion of their fatal crashes that were initiated by a rollover. The excess deaths resulting from rollover in the low-stability vehicles were strongly related to the stability variable (T/2/H) even when each of the subsets of the other variables was introduced.

Hazardous Mileage. As noted in the section on method, it has been argued that the utility vehicles which happen to have low stability are driven under very different conditions or by very different drivers than passenger cars. Without data on numbers of miles driven under these allegedly more hazardous conditions or by these allegedly more hazardous drivers, they assert, it is not possible to attribute the high rollover rates of vehicles such as the pre-1978 Bronco and the Jeep CJs to their high instability.

We were able to calculate the mileage that the pre-1978 Bronco and the Jeep CJs would have had to accumulate in rural and urban environments, on interstate and noninterstate roads, or by sex and age of drivers, as well as age of vehicles, if only the environments or drivers were responsible for their fatal rollovers. We knew the ratio of rollover rates per vehicle under these various conditions for the low stability vehicles and for passenger cars and we also had the best available estimates of average annual mileage of cars under some of these conditions and for age and sex of drivers. Therefore, we needed only to solve the equation of ratio of rollover rates equal to ratio of average miles, indicated in the method section, for the missing piece of information, average mileage required to be driven for the specific low-stability vehicles in question -- pre-1978 Broncos and Jeep CJs. Had the arguments concerning more hazardous conditions or more hazardous drivers been valid, we would have expected to find no unreasonable differences in total annual mileage driven for the pre-1978 Broncos or Jeep CJs, on one hand, and all passenger cars, on the other.

As noted previously, of variables other than stability of vehicle, the largest effect on percent rollover of all fatal crashes was that of rural environment. Estimates of mileage of vehicles in rural and urban environments are compiled annually by the Federal Highway Administration (FHWA). The year-to-year variation of annual miles per passenger car was from 9000 to 9600 in the years studied, with about 40 percent, on average, accumulated in rural areas. Motorcycle mileage was included in passenger car mileage by FHWA, but accounted for only about 4 percent of the total. Also, the cars on which center of gravity data were available were somewhat older and may not have had exactly the same average miles as all cars. Therefore, we performed three separate calculations to note the sensitivity of the estimates to accuracy of the car mileage data. In Table 3, the miles necessary for pre-1978 Broncos and Jeep CJs to roll over at the frequency per vehicle observed, if their fatal rollover rate per mile is the same as that for passenger cars

Table 3. Miles Necessary Under Rural and Urban Conditions for Pre-1978 Broncos and Jeep CJs If Their Rollover-Initiated Fatal Crash Rates Per Mile Under Those Conditions Were The Same As Passenger Cars

	Number	Per 100,000 Vehicles	Average Car Miles 7000	9500	12000
Rural					
Cars	751	1.6	2800	3800	4800
Pre-1978 Broncos	71	15.5	27125	36812	46500
Jeep CJs	229	13.0	22758	30875	39000
Urban					
Cars	173	0.4	4200	5700	7200
Pre-1978 Broncos	4	0.9	9450	12825	16200
Jeep CJs	61	3.5	36750	49875	63000

in the Federal Highway Administration estimates, are presented for assumed average annual car mileage of 9500, 7000, and 12,000.

For the per vehicle rate to be as high as that of the passenger cars, the total average annual miles for the pre-1978 Broncos would have had to exceed 36,000 miles (27,125 rural and 9450 urban) if car mileage averaged 7000 per year. If the FHWA estimate of around 9500 miles per year for the passenger cars was accurate, each pre-1978 Bronco would have to have been driven about 49,000 miles per year to result in the observed rollover rate per vehicle. If the passenger cars averaged as much as 12,000 miles per year, the pre-1978 Bronco would have to have been an average of more than 62,000 miles per year, assuming that rollovers were simply a function of mileage on differentially hazardous roads.

The results for the Jeep CJ were even higher for each category of the estimated car mileage. About 59,000 miles per CJ vehicle per year would have been necessary for the rate of rollovers per number of CJs registered, if one assumes comparable rollover rates for CJs and the passenger cars and the cars were driven about 7000 miles per year on average. If the annual average car mileage was 9500, the average annual CJ mileage would have to have been more than 80,000 under the same conditions. The result would have been more than 100,000 miles per vehicle per year if car mileage averaged 12,000 per year.

Whatever car mileage estimates were used within the range of reason, the results in average annual mileage of pre-1978 Broncos and Jeep CJs were far outside the range of plausibility. Therefore, it cannot be concluded that the excess fatal rollover rates per vehicle found for these vehicles is the result of the difference in hazards involved in rural versus urban driving.

A similar analysis was done for travel on Interstate versus other roads. According to the Federal Highway Administration, about 20 percent of the passenger car mileage occurred on Interstate highways. Assuming total average passenger car mileage of 9500 per year, as shown in Table 4, on the safest roads -- Interstate highways -- an average pre-1978 Bronco would have to have been driven 14,250 miles annually and the Jeep CJ 12,350 annually for the rollover-initiated crash rates of these vehicles per mile to have been the same as that of cars on interstate roads. The total average annual mileage, including interstates and other roads, would have been more than 70,000 for the pre-1978 Broncos and more than 70,000 for the Jeep CJs if one assumes that rollover-initiated fatal crashes were a function of type of road.

A separate source was used to calculate similar estimates by two important driver characteristics -- age and sex. A national survey in 1977 included self-reports of annual mileage by the respondents. The data were published by age and sex of drivers and have been used in previous studies to calculate the fatal crash rates for specific age groups (Robertson, 1983).

The issue here was whether the fatal rollovers in pre-1978 Broncos and Jeep CJs could be attributed to higher mileage driven by higher risk sex or age groupings. Table 5 presents the results of the estimates of miles necessary to produce the rollover-initiated fatal crashes observed if rollover were a function of

Table 4. Mileage Necessary On Interstate Highways and Other Roads For Utility Vehicles If Their Rollover-Initiated Fatal Crashes Are A Function of Mileage On These Roads Relative To That of Cars

	Number	Per 100,000 Vehicles	Average Annual Miles
Interstate Highways			
Cars	105	0.2	1900
Pre-1978 Broncos	7	1.5	14250
Jeep CJs	22	1.3	12350
Other Roads			
Cars	925	2.0	7600
Pre-1978 Broncos	68	14.8	56240
Jeep CJs	269	15.3	58140

differential mileage by men and women. The average woman driver of a pre-1978 Bronco would have to have driven it some 33,000 miles per year and the average woman Jeep CJ driver would have to have driven it some 28,000 miles per year if the observed rollovers were the result of mileage comparable to car mileage by women drivers. Male drivers of pre-1978 Broncos would have to have driven them an average of about 119,000 miles per year and male Jeep CJ drivers would have to have driven them an average of about 123,000 miles per year to have had the fatal rollovers observed relative to those observed for males driving cars at the average mileage. The mileage necessary for the rollover rates per vehicle of utility vehicles were so far outside the range of plausibility as to refute the argument that fatal rollovers could be a result of differential use of the vehicles by the sexes.

Table 6 shows the estimated mileage necessary to obtain the rollover-initiated fatal crash rates in drivers from different age groups using utility vehicles, if differential mileage by age accounted for the difference in their rates per vehicle relative to passenger cars. In every age group the necessary mileage was outside the range of reason, and in most wildly so. In the 20 to 44 year old groupings, the driver ages in which two-thirds of fatal rollovers in the utility vehicles occurred, the average annual miles necessary for pre-1978 Broncos to have the observed rate per vehicle relative to cars ranged from 70,000 to 260,000. The comparable range for the Jeep CJ was 80,000 to 144,000. In several age groups the necessary annual miles exceeded those that most vehicles would accumulate during their lifetime use. Among teenagers, the annual estimates of about 41,000 miles per driver

Table 5. Estimated Annual Average Miles Necessary For Women and Men Pre-1978 Bronco Drivers and Jeep CJ Drivers If Rollover-initiated Fatal Crash Rates of These Vehicles Result From Differential Mileage of the Sexes

	Number	Per 100000 Vehicles	Average Miles Per Year
Women			
Cars	175	0.4	5943
Pre-1978 Bronco	10	2.2	32686
Jeep CJ	33	1.9	28229
Men			
Cars	750	1.6	13363
Pre-1978 Bronco	65	14.2	118597
Jeep CJ	258	14.7	122772

Table 6. Average Annual Mileage In Utility Vehicles By Drivers In Specific Age Groups Necessary For The Rollover-Initiated Fatal Crash Rate Per Vehicles To Be The Same As That For Cars Driven By Drivers In The Same Age Groups

Age	Fatal Rollovers	Per 100000 Vehicles	Average Annual Miles
Teenagers			
Cars	237	0.51	5662
Pre-1978 Bronco	17	3.70	41077
Jeep CJ	77	4.38	48626
20-24			
Cars	271	0.58	10260
Pre-1978 Bronco	21	4.57	80842
Jeep CJ	80	4.55	80488
25-29			
Cars	132	0.28	11337
Pre-1978 Bronco	8	1.74	70451
Jeep CJ	52	2.96	119848
30-34			
Cars	94	0.20	11634
Pre-1978 Bronco	10	2.18	126810
Jeep CJ	37	2.11	122739
35-39			
Cars	57	0.21	12244
Pre-1978 Bronco	3	0.65	66322
Jeep CJ	25	1.42	144887
40-44			
Cars	27	0.06	11898
Pre-1978 Bronco	6	1.31	259773
Jeep CJ	10	0.57	113031
45 and Older			
Cars	106	0.23	9083
Pre-1978 Broncos	10	2.18	86091
Jeep CJ	10	0.57	22510