

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.

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

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.		Rice, et al.	
		CG	T/2/H	CG	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
AMC Gremlin	57.50			22.1	1.24
Volkswagen Beetle	52.45	19.38	1.35	21.5	1.34
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 Chev- rolet 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

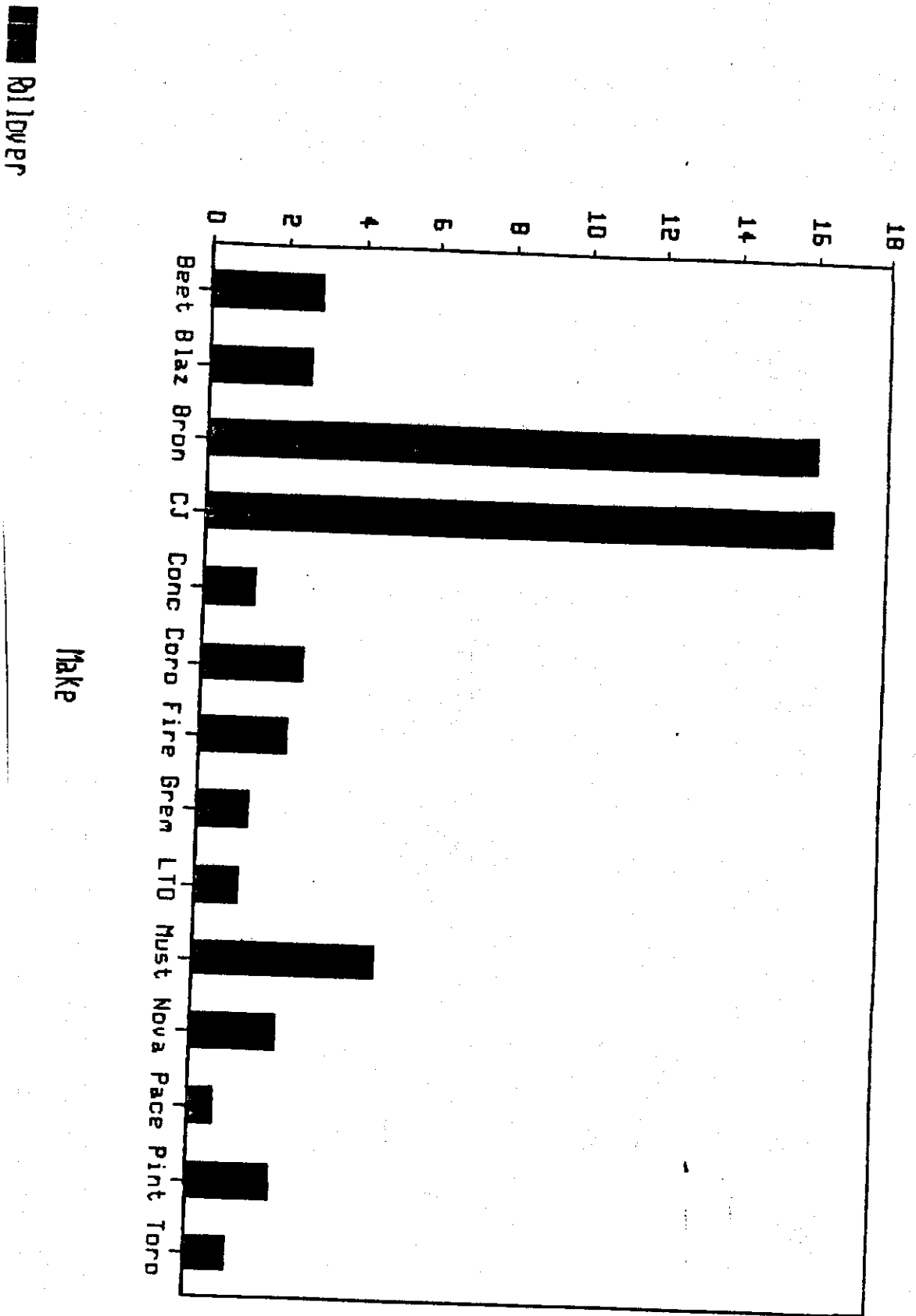


FIGURE 1

Fatal Single Vehicle Nonroll Per 100,000

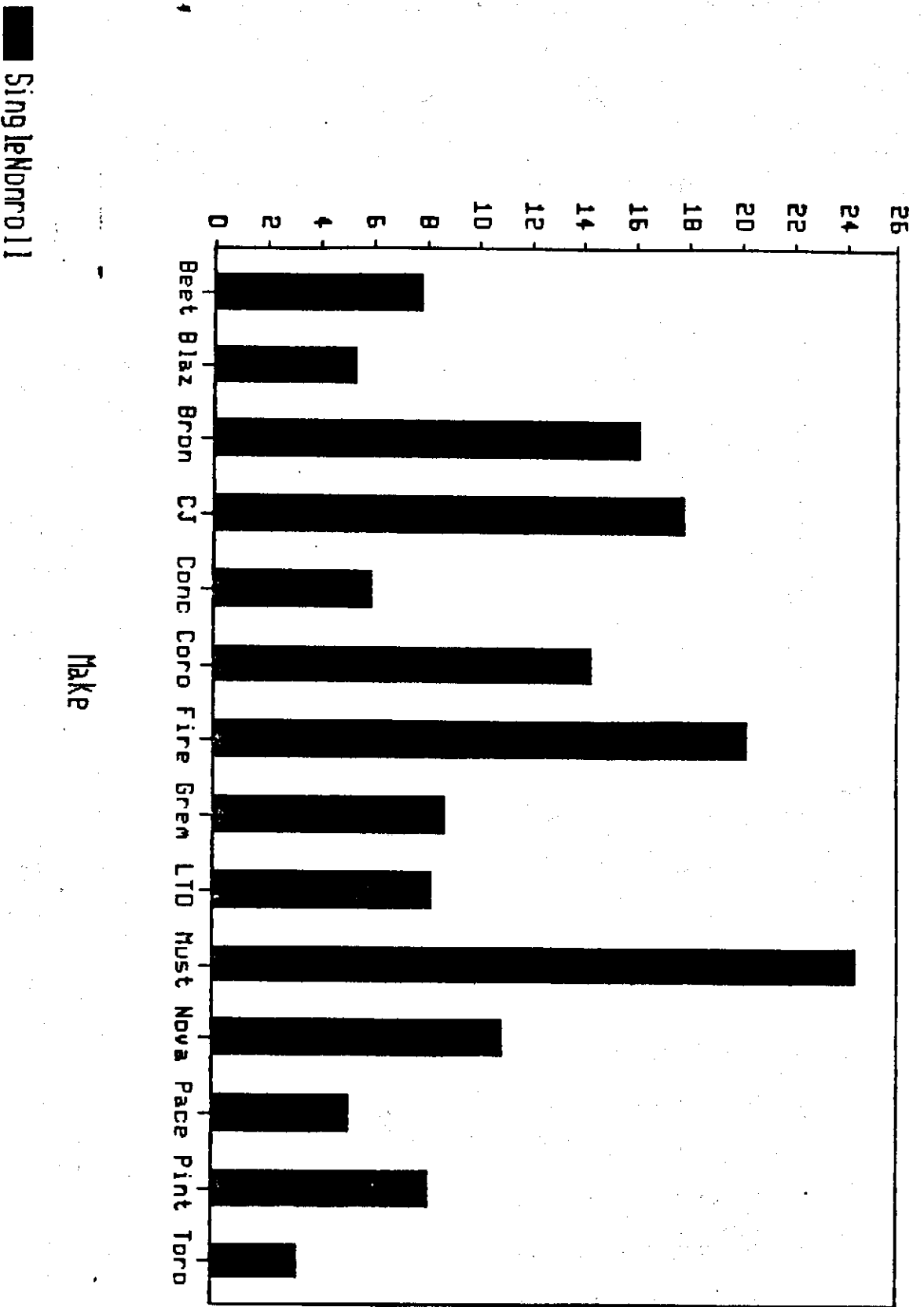


FIGURE 2

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.

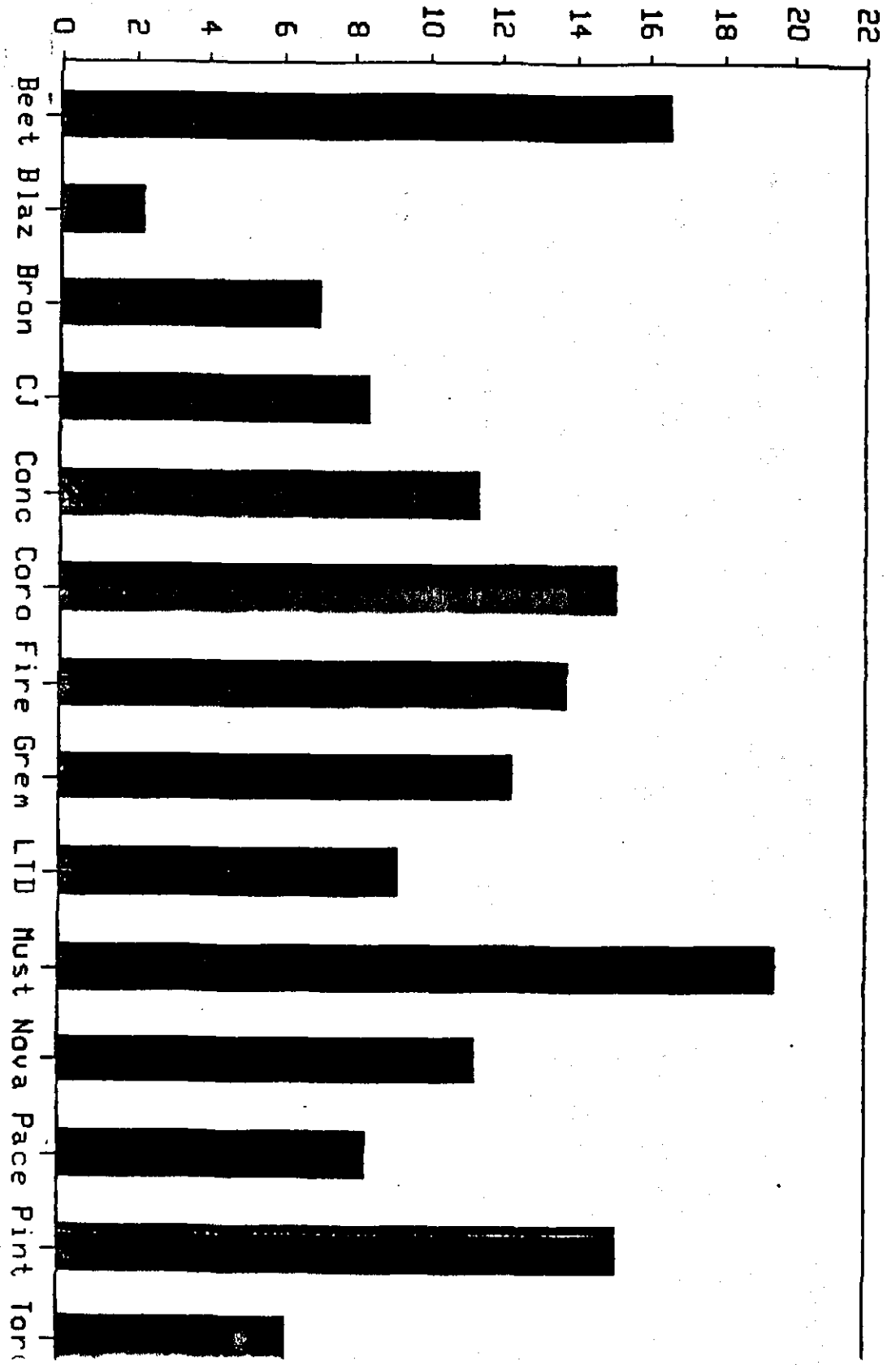
In the following analysis, the percent of all fatal crashes that were rollovers is examined in relation to the stability formula, $T/2/H$, of the vehicle, where T equals the width in inches between wheels and H equals the height in inches of the center of gravity.

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

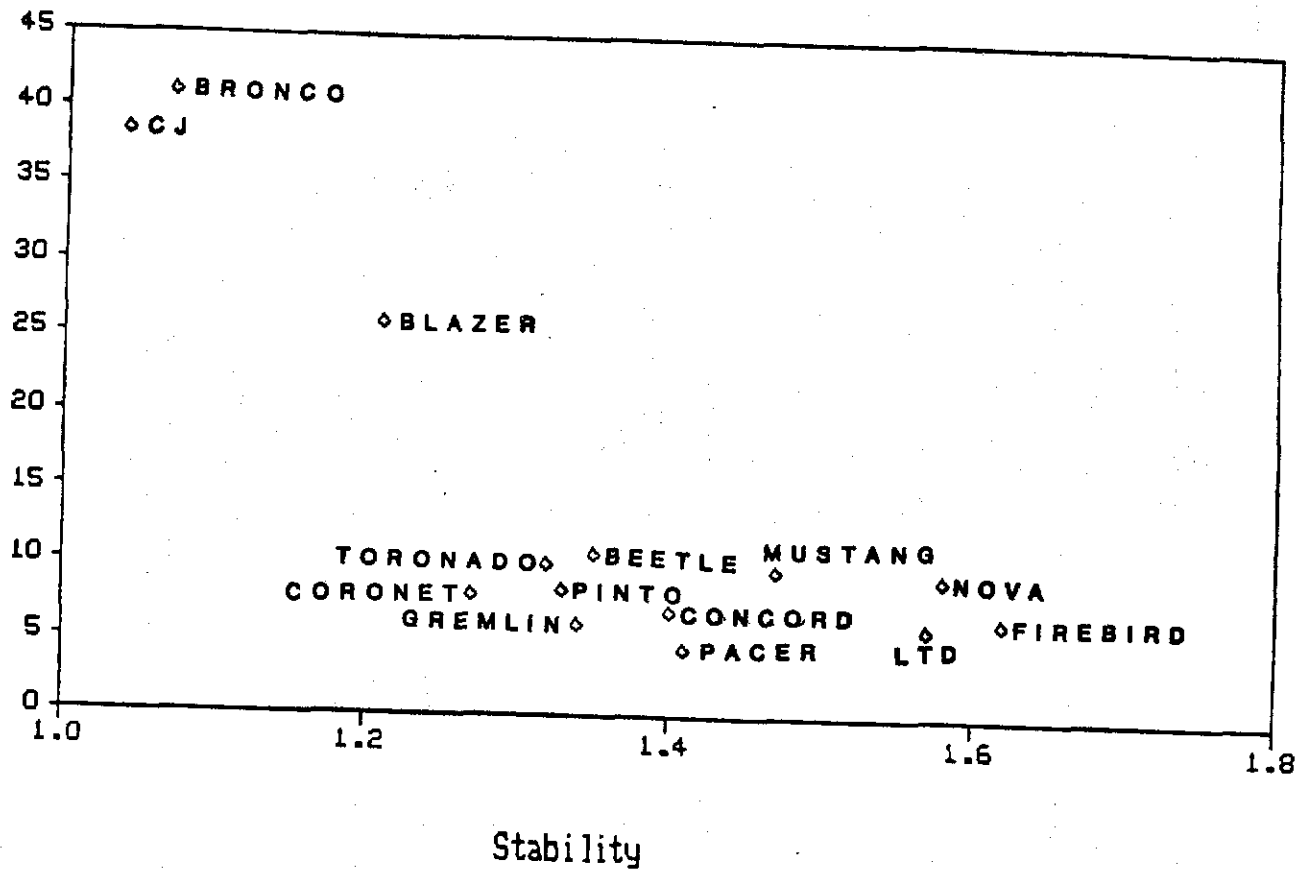


Multiple

FIGURE 3

Make

Percent Rollover of All Fatal Crashes



◇ Vehicle

FIGURE 4

$$\text{Percent Rollover} = 90.5 - 56.7(T/2/H)$$

Percent variance explained = 65