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An Evaluation of Door Locks and Roof Crush Resistance of Passenger Cars— Federal Motor Vehicle Safety Standards 206 and 216

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An agency staff review of existing Federal regulations performed in response to Executive Order 12291.

16. Abstract

Federal Motor Vehicle Safety Standard 206 - Door Locks and Door Retention Components - is aimed at reducing the likelihood of occupant ejection in crashes. The industry steadily improved door lock design during the 1960's. Standard 216 - Roof Crush Resistance - is designed to reduce deaths and injuries due to the crushing of the roof into the passenger compartment in rollover crashes. Hardtops were redesigned as pillared cars, with stronger roof support. This evaluation analyzes the effectiveness and benefits of stronger door locks and roof structures in rollover crashes of passenger cars. It also estimates the cumulative effect on fatality risk - for unrestrained occupants in rollover crashes - of all safety standards and vehicle modifications of the 1963-82 era. The study is based on statistical analyses of FARS, Texas, NCSS, NASS and MDAI data and roof crush tests on pre- and post-Standard 216 cars. It was found that:

- o Door latch improvements implemented during 1963-68 save an estimated 400 lives per year, reducing the risk of ejection in rollover crashes by 15 percent.

- o The shift from hardtops to pillared cars, in response to Standard 216, saves an estimated 110 lives per year.

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LIST OF ABBREVIATIONS

ACIR	Automotive Crash Injury Research
AIS	Abbreviated Injury Scale
AMC	American Motors Corporation
CDC	Collision Deformation Classification
c.g.	center of gravity
CY	calendar year
Delta V	velocity change during impact
exp	inverse of the natural logarithm
FARS	Fatal Accident Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GM	General Motors Corp.
HSRI	Highway Safety Research Institute, now called UMTRI
HT	hardtop
MDAI	Multidisciplinary Accident Investigation
mph	miles per hour
MY	model year
n.a.	not applicable
NASS	National Accident Sampling System
NCSS	National Crash Severity Study
NHTSA	National Highway Traffic Safety Administration
NPRM	Notice of Proposed Rulemaking
PSI	inverse cumulative normal (probit) function
R	correlation coefficient
SAE	Society of Automotive Engineers

SAS	Statistical Analysis System
SSROC	sum of the squares of the rank order correlations
SW	station wagon
TP216-03	compliance test procedure for Standard 216, 3rd edition
VIN	Vehicle Identification Number
VW	Volkswagen

SUMMARY

Executive Order 12291 (February 1981) requires agencies to evaluate their existing regulations. The objectives of an evaluation are to determine the actual benefits - lives saved, injuries prevented, damage avoided - and costs of safety equipment installed in production vehicles in connection with a standard.

The goal of this report is to evaluate the life saving benefits associated with Federal Motor Vehicle Safety Standards 206 and 216 for unrestrained occupants of passenger cars. Standard 206 - Door Locks and Door Retention Components - took effect on January 1, 1968 and is aimed at "minimizing the likelihood of occupants being thrown from the vehicle as a result of impact." Standard 216 - Roof Crush Resistance - has applied to passenger cars since September 1, 1973 and its purpose "is to reduce deaths and injuries due to the crushing of the roof into the passenger compartment in rollover accidents." Vehicle modifications in response to these standards have been piecemeal and gradual. The domestic auto industry anticipated Standard 206 by many years and had been making incremental year to year improvements in door design throughout 1956-68. Standard 216 took effect in the middle of the gradual change in roof styling from true hardtops to pillared hardtops, a process which stretched over most of the 1970's (and may have been motivated by other factors in addition to Standard 216).

It is best to study Standards 206 and 216 in the context of the overall trend in fatality risk of unrestrained occupants of passenger cars of model years 1963-82 in rollover crashes, for this is the type of crash in which strong roofs and better door locks are especially likely to have benefits. Standards 206 and 216, however, are not the only vehicle factors which affected fatality risk in rollover crashes during the 1963-82 period. A major task of the evaluation is to study the overall fatality trend and identify what changes are due to improved door locks and roof crush strength, as opposed to other vehicle factors.

Rollover crashes are a major safety problem, resulting in about 4,000 fatalities a year to occupants of passenger cars. A noteworthy aspect of rollovers is that many of the fatal crashes do not involve great amounts of force or destruction to the car. Two thirds of the fatalities in rollovers involve occupants being ejected from the car, often in crashes with low damage.

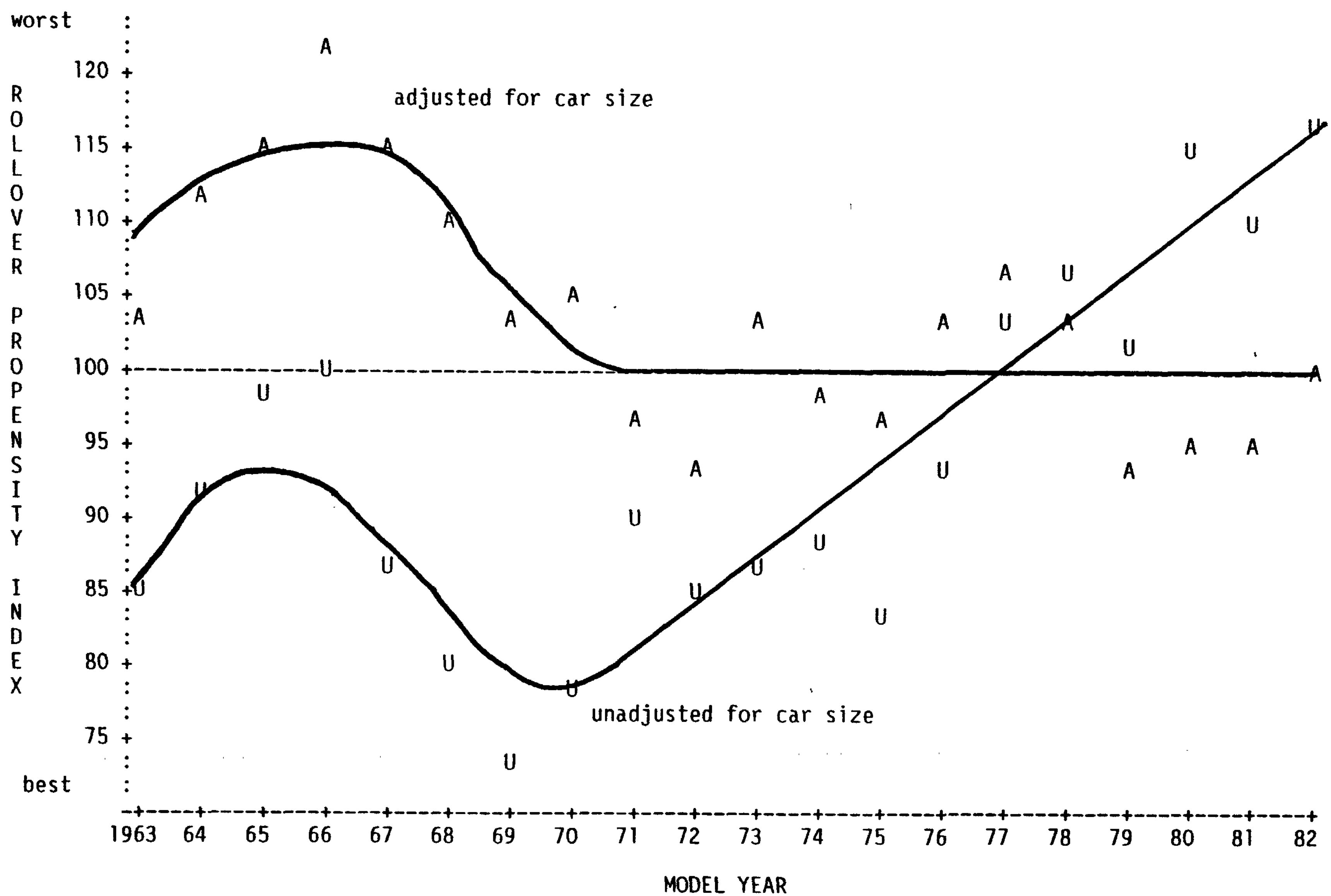
A number of strategies are available to reduce deaths and injuries in rollovers. The best single measure is to use safety belts. Recent studies have shown that belts are exceptionally effective in rollovers, reducing fatality risk by 70 percent or more. Many occupants do not use manual safety belts, however, especially those who are likely to become involved in severe rollovers.

A first line of defense against rollover fatalities is to prevent a car from rolling over. The next line of defense is to keep the occupant inside the car. As noted above, many of the ejections occur in crashes of low severity. The design of doors and their locks, latches and hinges is crucial here; so is the retention and integrity of windows. Next, the occupants' living space within the passenger compartment must be maintained. The roof has to be strong enough to resist severe compression when the car rolls over. Finally, impacts with the interior surfaces of the passenger compartment should not injure the occupants.

The principal analysis technique of the evaluation is to define and compute year to year trend lines or risk indices: e.g., an overall fatality risk index, a crashworthiness index and a roof crush strength index.

The first set of trend lines generated in the evaluation is shown in Figure 1. The curve connecting the U's on the figure is the rollover propensity index for passenger cars by model year. It is based on Texas accident data; rollover propensity is the ratio of rollovers to frontal impacts with fixed objects, with some adjustments. This measure of "rollover propensity" combines the concepts of directional stability (tendency of cars to stay under the driver's control and on the road) and rollover stability (tendency of cars to remain upright, given exposure to off-road tripping mechanisms). The rollover propensity index starts at a level close to 85 in model year 1963 and briefly rises to the 90's before dropping to a low of about 80 by 1970. After model year 1970, rollover propensity rises steadily year after year to an all time high close to 120 in model year 1982. It is well known from the literature that rollover

FIGURE 1: ROLLOVER PROPENSITY INDEX BY MODEL YEAR (1975-80 average = 100)



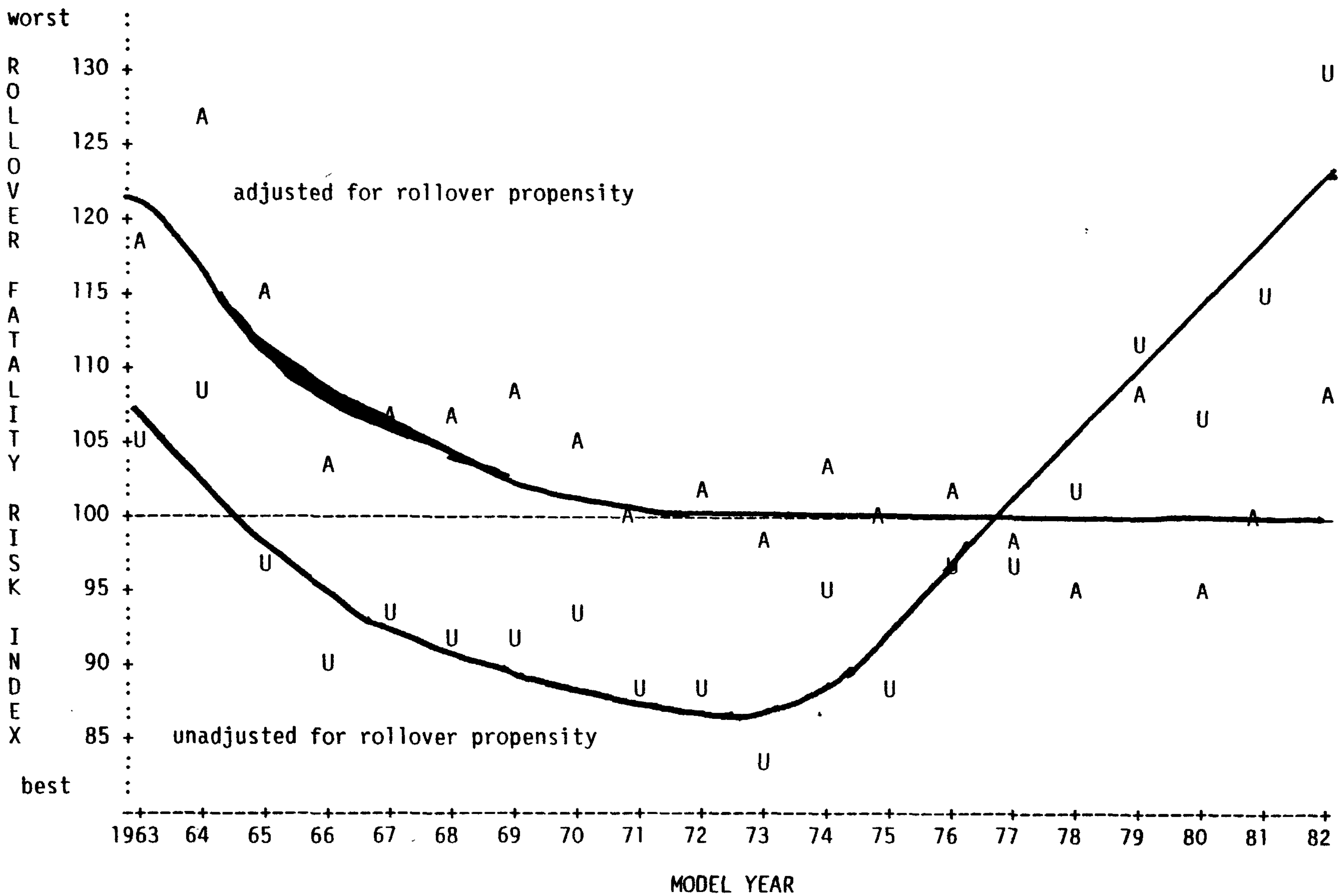
propensity is highly correlated with car size parameters such as track width, wheelbase, curb weight, or the height of the center of gravity, although it is not clear which one of those intercorrelated parameters is more influential than the others. Obviously, the steady increase in rollover proneness after 1970 coincides with the trend to vehicle downsizing and the shift from wide, long and heavy domestic cars to narrower, shorter and lighter imports and subcompacts.

The evaluation is not an investigation of the "causes" of rollover. Nevertheless, the approach used to calculate the benefits of vehicle modifications necessitates checking if there are any important factors besides car size significantly correlated with rollover proneness. A statistical analysis of the Texas data shows that much of the variation across makes, models and model years can be explained by car size parameters such as track width, wheelbase and curb weight - with <u>one</u> important exception: the pre-1969 Volkswagen Beetle had a rollover rate even beyond what would be expected from its narrow, short and light design. The curve connecting the A's in Figure 1 is the rollover propensity index after <u>adjustment</u> for year to year changes in track width, curb weight and wheelbase. It starts at 110 and rises in the mid 1960's as the Volkswagen Beetle became more popular. During 1967-69, following important changes in the suspension and wheels of Volkswagen Beetles, the index drops quickly to 100 and it has remained essentially unchanged since 1970. There may have been other models with exceptional rollover rates, but none of them had sufficiently high sales or extreme rollover rates to pull the index (average for all cars) away from 100. Rollover propensity, on the average, has become very well correlated with car size.

The curve connecting the U's in Figure 2 is the most comprehensive measure of vehicle performance in this evaluation. It is the overall rollover <u>fatality risk index</u> for passenger cars by model year, comprising the net effects of changes in rollover propensity <u>and</u> crashworthiness. It is based on Fatal Accident Reporting System data; fatality risk is the ratio of fatalities in rollovers to those in frontal impacts with fixed objects, with some adjustments. The fatality risk index starts at about 107 in model year 1963 and drops quickly at first, then more slowly to a low in the upper 80's by model year 1973. After model year 1975, the fatality index rises at an increasing rate year after year to an all time high of about 123 in model year 1982. In other words, an occupant of a 1982 car has 15 percent higher likelihood (123/107) of dying in a rollover crash than a 1963 car occupant, under similar driving conditions.

The principal reason that newer (smaller) cars have higher rollover fatality risk is that they have higher rollover propensity: the more rollovers, the more deaths. A major task of the evaluation is to separate out the effects of changes in crashworthiness from changes in rollover propensity. The curve connecting the A's in Figure 2 is the <u>crashworthiness index</u> for rollovers: rollover fatality risk adjusted for rollover propensity. Here, the results are more favorable for new cars. The crashworthiness index starts at just over 120 in model year 1963 and drops quickly at first, then more slowly till it reaches 100 in the early 1970's. It has been close to 100 since model year 1975.

FIGURE 2: ROLLOVER FATALITY RISK INDEX BY MODEL YEAR (1975-80 average = 100)



More detailed fatality indices make it possible to study the effects of individual vehicle modifications. Figure 3 is the crashworthiness index for ejection fatalities only, relevant to the analysis of door locks and Standard 206. Ejectees account for two thirds of the rollover fatalities. The ejection fatality risk index starts at about 125 in model year 1963 and drops sharply during the mid 1960's, when the manufacturers significantly improved door latches. It continued to drop at a slower rate during the late 1960's, as manufacturers implemented further improvements. (A small portion of the reduction may be due to adhesive bonding of the windshield, a vehicle modification associated with Standard 212.) The ejection index reached 100 in 1970-71 and has stayed close to 100 ever since.

Figure 4 is the corresponding crashworthiness index for occupants who were killed without being ejected. In general this is a far more severe group of crashes, for close to 75 percent of ejectees would have survived if they had stayed in the car. The nonejection fatality index is close to 108 throughout the 1960's. During model years 1972-76, as true hardtops were changed to pillared hardtops, the index drops to 100 and it stays close to 100 thereafter. A separate analysis of fatality risk in hardtops and sedans confirms that the fatality reduction is due to changes from true to pillared hardtops.

The roof crush strength of passenger cars was studied in laboratory tests and accident data. The Standard 216 compliance test data base of 108 new, post-standard cars was supplemented by 20 tests of used

FIGURE 3: ROLLOVER EJECTION FATALITY RISK INDEX BY MODEL YEAR
(Adjusted for rollover propensity; 1975-80 average = 100)

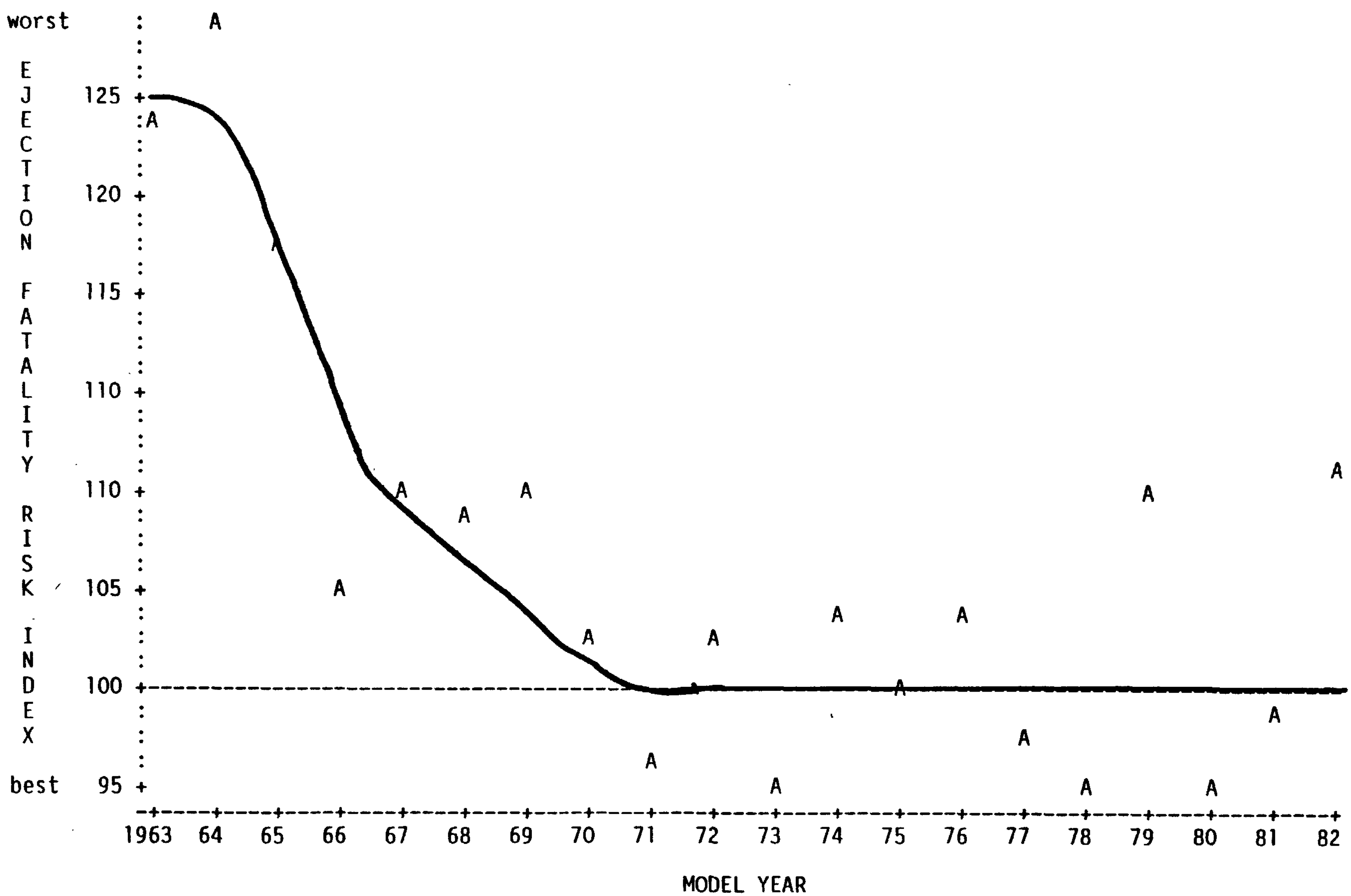
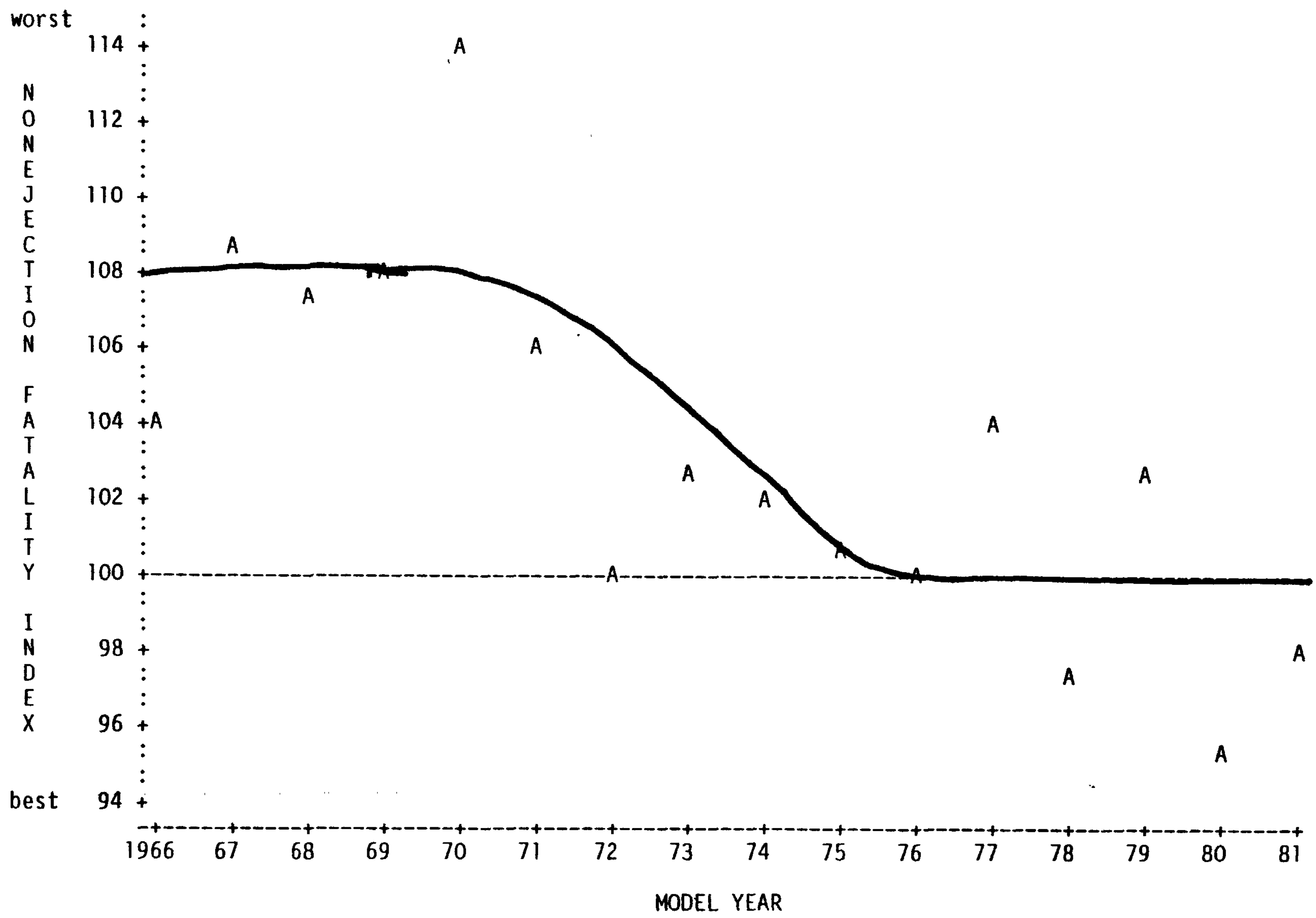


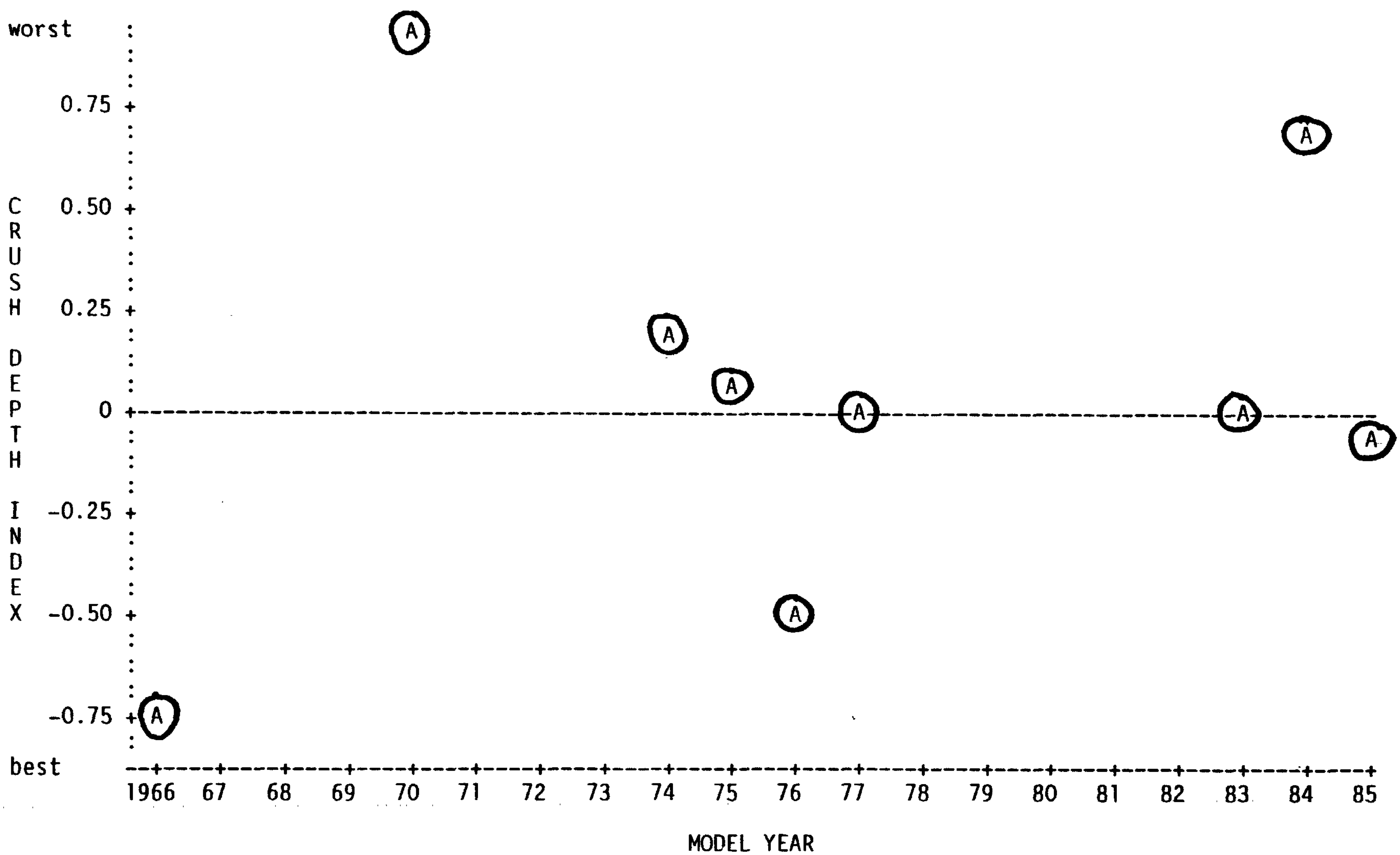
FIGURE 4: ROLLOVER NONEJECTION FATALITY RISK INDEX BY MODEL YEAR
(Adjusted for rollover propensity; 1975-80 average = 100)



cars, including 14 pre-standard vehicles. Figure 5 is an index of the average performance on the Standard 216 test by model year. The index is obtained by statistically transforming the actual inches of crush to a normal variable and adjusting for biases that happened because some of the test samples emphasized certain manufacturers or market classes. The crush depth index is zero for the average car, negative for a stronger than average roof, positive for weaker; the index values do not readily translate back to actual inches of crush. Cars of the mid 1960's actually had the strongest roofs on the tests, with a normalized average crush depth of -0.7. In the later 1960's, large cars emphasized a look with a wide, flat roof. That resulted in weaker roof crush performance, with a normalized crush depth of +0.9 in model year 1970. From model year 1974 onwards (post-Standard 216), roof crush resistance is better than in 1970 and the normalized score is usually close to 0 (average strength). A more detailed look at the laboratory test results shows that most cars easily exceeded the requirements of Standard 216, even before the standard took effect. About half the cars with marginal performance on the Standard 216 test were full-sized hardtops, although not all hardtops had that problem. The elimination of true hardtops during the 1970's helped eliminate many of the marginal performers.

The Standard 216 compliance test is only one way of measuring roof strength. Another is to look at the actual amounts of roof crush in rollover accidents. The extent of roof crush is documented in the Collision Deformation Classification by a scale ranging from 1 (minimal damage) to 9 (extreme damage), in data on the National Accident Sampling

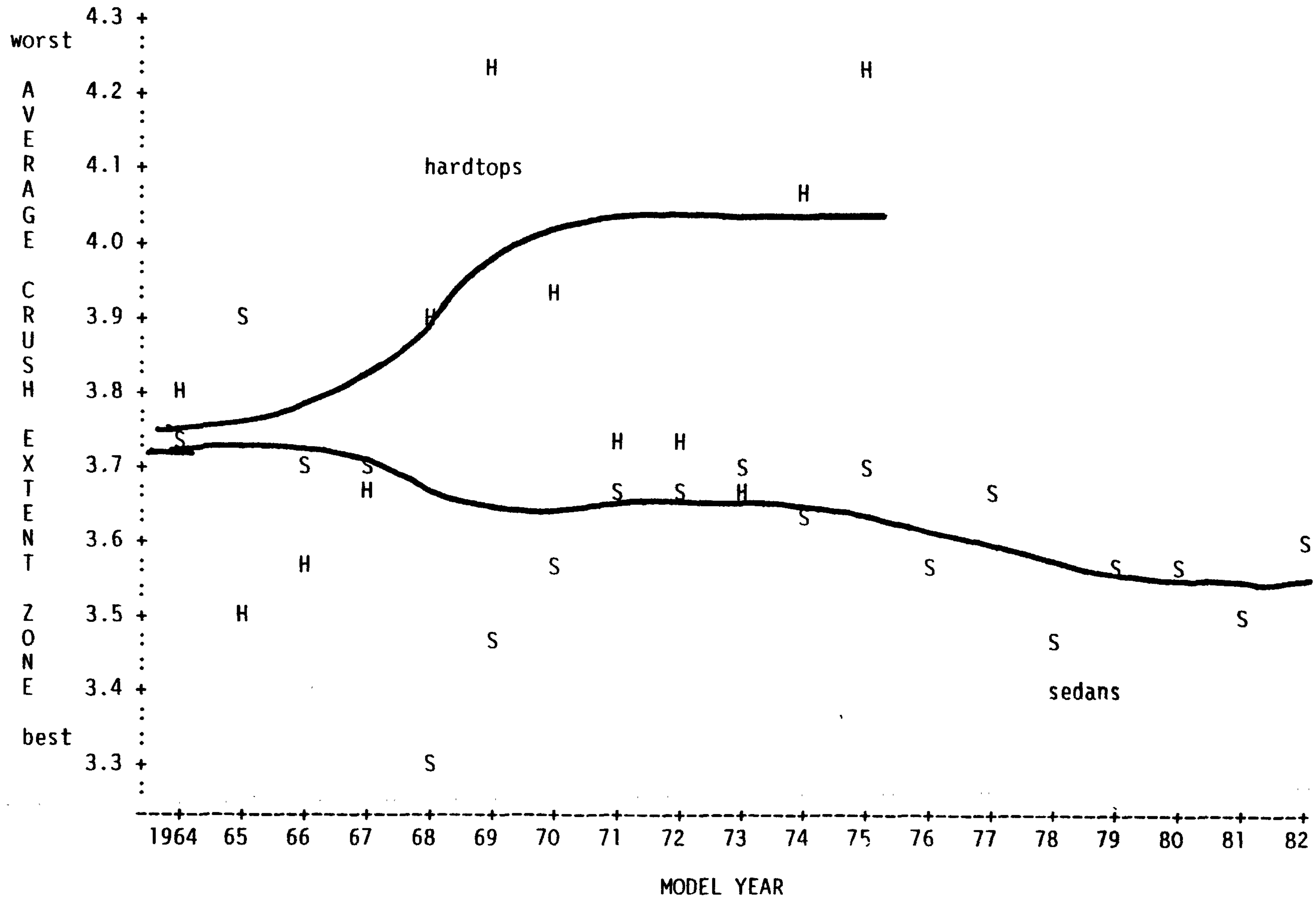
FIGURE 5: ROOF CRUSH DEPTH IN STANDARD 216 TESTS BY MODEL YEAR
(Normalized and adjusted for market class and manufacturer)



System, National Crash Severity Study and Multidisciplinary Accident Investigation files. After the data are corrected for reporting differences between the files and adjusted for car size, the average crush depth rating is graphed by model year in Figure 6. The curve connecting the S's indicates the trend in crush for sedans, pillared hardtops and other cars with full B pillars. Roof performance hardly changed during 1963-82, dropping from an average of 3.7 crush zones in cars of the mid 1960's to 3.6 by the early 1980's. The curve connecting the H's depicts the trend in crush for true hardtops. During the mid 1960's, they were about as strong as sedans. Throughout 1968-75, true hardtops had significantly weaker roofs than pillared cars, with crush extending 4 zones on the average. The elimination of true hardtops in the 1970's helped improve the overall average roof crush strength of cars. In summary, the analyses show that certain hardtop designs had weaker roofs and higher nonejection fatality rates in rollovers than other cars of the same size. The elimination of those designs saved lives.

The critical problem in developing safety indices for motor vehicles is separating the true effects of vehicle modifications from other factors that could bias the indices: changes in driving habits, changes in roadway or exposure patterns, year to year inconsistencies of definitions or reporting on accident data files. There are no algorithms for identifying and removing biases; it is up to the analyst to judge what is a bias and what is the best method to remove it. The validity of the indices in Figures 1-6 depends on these judgments. The accident and test data used in this evaluation contain generous samples for cars of the

FIGURE 6: ROOF CRUSH EXTENT IN ROLLOVER CRASHES BY MODEL YEAR
(Adjusted for car size)



1970's but thins out for the oldest and youngest cars. That made it impossible to study cars before 1963 or after 1982 and even for 1963-64 and 1981-82 the sampling errors are visibly larger than for the middle years.

One complication in the analyses is that vehicle size parameters such as track width, wheelbase and curb weight are highly intercorrelated - i.e., "large" cars tend to be wider, longer <u>and</u> heavier than "small" cars. While the statistical analyses used here accurately identify the increase in rollover propensity for the typical small car relative to the typical large car, they may err in estimating what portion of the increase is attributable to any one parameter. Specifically, it is inadvisable to use the formulas of this report to predict what might happen in the future if a single parameter (say, curb weight) is changed while others are held constant.

The evaluation of Standard 206 is limited to passenger cars in rollover crashes. The standard also applies to light trucks, vans and multipurpose vehicles and it is likely to have benefits in side impacts as well as rollovers; however, those additional benefits could not be estimated by the approach used in this report.

The results in this report are based on a population of mostly unrestrained occupants. During the years of data covered in the report, belt usage in rollover crashes was too low to provide a sample adequate for the analysis of Standards 206 and 216 for belt users.

Despite the benefits associated with improved door locks and roof crush resistance, rollover crashes continue to account for a high percentage of fatalities in passenger cars, light trucks and utility vehicles. Thousands of occupant fatalities involve ejection through side windows or open doors. NHTSA has undertaken a comprehensive research and rulemaking program to find ways to reduce the number of rollover crashes and to protect occupants in those crashes. The agency is developing new accident data bases to improve understanding of the causes of actual rollover crashes. Mathematical and computer models are being developed to simulate vehicle dynamics and occupant kinematics in rollovers. Staged rollover crashes provide data for validating the simulation models and preliminary design of a "standard" rollover test facility. The agency is studying the strength of current door lock systems and developing glass plastic side windows designed to reduce the risk of occupant ejection in crashes. In September 1988, NHTSA granted a petition for rulemaking to establish a standard to protect against unreasonable risk of rollover. The proposed upgrade of the side impact protection standard includes a requirement that the doors remain closed during the impact test; the objective is to reduce the risk of occupant ejection through open doors.

The ultimate goal of the evaluation is to identify the individual vehicle modifications that affected fatality risk during the 1963-82 period and estimate the change in fatalities for each of them. Based on an examination of the trends in Figures 1-6 as well as more detailed analyses, the study's principal findings and conclusions on the individual vehicle changes are the following:

Principal Findings

Side door performance

- A number of significant improvements to door latches and locks of domestic and imported cars were implemented during 1963-68. They save an estimated 400 lives per year by preventing about 15 percent of the ejections in rollover crashes.

- Cars with 2 doors have 28 percent higher ejection risk in rollovers than 4 door cars, even after adjusting for differences in car size and exposure patterns. The market shift from 43 percent 2 door cars in model year 1963 to 67 percent in 1974-75 resulted in an increase of 150 fatalities per year.

- Conversely, the market shift from 67 percent 2 door cars in 1974-75 back to 45 percent 2 door cars by 1982 has saved 140 lives per year.

Roof crush resistance

- True hardtops have approximately 15 percent higher risk of a nonejection fatality in a rollover crash than pillared cars of the same size and exposure pattern.

- During the 1970's, true hardtops were restyled as pillared hardtops or sedans, saving an estimated 110 lives per year.

- 13 of 128 cars tested had "marginal" performance on Standard 216 (more than 4 inches of roof crush at a force level 10 percent above the Standard 216 requirement). Six of these 13 cars were full-sized hardtops.

Other findings

- Narrower, lighter, shorter cars have higher rollover rates than wide, heavy, long ones under the same crash conditions. During 1970-82, as the market shifted from large domestic cars to downsized, subcompact or imported cars, the fleet became more rollover prone. That may have been partly offset by increases in the track width of some imported cars after 1977. The net effect of all car size changes since 1970 is an increase of approximately 1340 rollover fatalities per year.

- Before 1969, the Volkswagen Beetle with the swing axle suspension had an even higher rollover rate than would be expected for a car of its size. Redesign of the suspension and wheels during model years 1967-69 brought the rollover rate down to the expected level, saving 280 lives per year.

- The fatality or injury rate per 100 rollover crashes is not a valid measure of crashworthiness in comparisons of cars of different sizes. Cars that tend to roll over easily (small, narrow cars) do so in crashes of intrinsically low severity. These rollovers have low injury rates. Larger cars would not roll over at all in those circumstances; when they do roll over it's a severe crash likely to result in injuries. The fatality rate per 100 crashes is lower for small cars, even if they are no more crashworthy.

Summary of annual effects of vehicle modifications on rollover fatalities

Vehicle Modification	Date	Lives per Year Saved	Lives per Year Lost
Improved door locks (Standard 206)	1963-69	400	
Shift from 4 door to 2 door cars	1963-74		150
Adhesive bonding of the windshield	1963-82	40	
Improved suspension for Volkswagen	1967-69	280	
Shift to subcompact & imported cars	1970-82		1220
Curtailed production of true hardtops (Standard 216)	1971-77	110	
Downsizing of existing car lines	1975-82		350
Shift from 2 door back to 4 door cars	1976-82	140	
Wider tracks for some imported cars	1977-82	230*	
		Saved	Lost
	SUBTOTALS	1200	1720
	NET LIVES LOST PER YEAR		520

*Preliminary estimate, due to complexity of identifying the effects of individual size parameters

Conclusions

- The door latch, lock and hinge improvements implemented in advance or in anticipation of Standard 206 have significantly reduced ejections and fatalities in rollover crashes.

- Before Standard 206, the side door was the primary avenue of fatal ejection in passenger car rollovers. Now it is the side window.

- Prior to Standard 216, the roof crush problem was mainly a problem of cars with true hardtop design. The restyling of true hardtops as pillared vehicles significantly reduced fatalities in rollover crashes.

- Vehicles other than true hardtops, such as sedans, coupes, station wagons or hatchbacks, experienced little change in roof crush strength throughout 1965-85.

- Since model year 1969, the rollover proneness of cars has had excellent correlation with vehicle size parameters such as track width, curb weight, or wheelbase (although the methods of this report do not identify which individual parameter is the principal "cause" of rollover proneness).

CHAPTER 1

INTRODUCTION AND BACKGROUND

1.1 Evaluation of NHTSA regulations and programs

Executive Order 12291, dated February 17, 1981, requires Federal agencies to perform evaluations of their existing regulations [27]. The evaluations should determine the actual costs and actual benefits of existing rules. More recently, Executive Order 12498, dated January 4, 1985, requires agencies to develop a regulatory planning process including publication of plans to review existing regulations pursuant to Executive Order 12291 [28].

The National Highway Traffic Safety Administration began to evaluate its existing Federal Motor Vehicle Safety Standards in 1975 [51]. Its goals have been to monitor the actual benefits and costs of safety equipment installed in production vehicles in response to standards. More generally, evaluations compare a standard's actual on the road performance and effectiveness with goals that may have been specified when the rule was initially promulgated - e.g., in its preamble, regulatory impact analysis, or other supporting documents - including analyses of possible benefits or impacts that had not been originally anticipated. The agency has published 17 comprehensive evaluations of safety standards or other vehicle programs to date. NHTSA intends to evaluate every one of its safety standards that can be associated with a tangible, clearly defined modification in production vehicles and whose costs and benefits can be measured by analyzing data on production vehicles.

1.2 Standard 206 - Door Locks and Door Retention Components

Federal Motor Vehicle Safety Standard 206 "specifies requirements for side door locks and side door retention components including latches, hinges, and other supporting means, to minimize the likelihood of occupants being thrown from the vehicle as a result of impact" [6]. Already in the early 1960's, occupant ejection was known to be the main cause of deaths in rollovers and a serious problem in other crash modes as well [43], [82]. The standard has applied to passenger cars since January 1, 1968, multipurpose passenger vehicles since 1/1/70 and trucks since 1/1/72.

The current standard for passenger cars includes requirements for latches, hinges and locks. "Each door latch and striker assembly shall be provided with ... a fully latched position and a secondary latched position." The door latch and striker assembly shall not separate when a longitudinal load of 2500 pounds is applied in the fully latched position, or 1000 pounds in the secondary latched position. It shall not separate when a transverse load of 2000 pounds is applied in the fully latched position, or 1000 pounds in the secondary latched position. "The door latch shall not disengage from the fully latched position when a longitudinal or transverse inertia load of 30 g is applied to the door latch system (including the latch and its actuating mechanism)." Door hinges shall not separate when a longitudinal load of 2500 pounds or a transverse load of 2000 pounds is applied. In addition to the strength requirements, the standard guards against inadvertent door opening: when the front door is locked, the outside door handle shall be inoperative. When the rear door is locked the inside and outside door handles shall be inoperative.

Standard 206 has a regulatory history that began before NHTSA was founded. Specifically, it incorporates two SAE standards developed by the domestic auto industry. SAE Standard J839, "Passenger Car Side Door Latch Systems," was originally approved in November 1962 [72], p. 893. It defined the longitudinal, transverse and inertial strength tests for door latches subsequently incorporated into Standard 206. But in the original version, the strength requirements were only 1500 pounds in the longitudinal test and fully latched position, 1000 pounds transverse/fully latched and 500 pounds for either test in the secondary latched position. It was superseded in May 1965 by Standard J839b [73], p. 904, which raised the strength requirements to the levels currently in Standard 206. SAE Standard J934, "Vehicle Passenger Door Hinge Systems," approved July 1965, embodies the current Standard 206 hinge test [73], p. 906.

The Notice of Proposed Rulemaking published by NHTSA's predecessor on December 3, 1966 included Standard 206 among the initial safety standards [18]. The proposed effective date was September 1, 1967. The proposed standard incorporated both SAE standards. It did not include the requirement that door handles be inoperative when the doors are locked but it included all the other requirements which Standard 206 places on passenger cars today (1989). The proposal became a Final Rule on February 3, 1967 [19] and the effective date was postponed to January 1, 1968 [21]. Also on 1/31/67, the agency published an Advance Notice of Proposed Rulemaking with the intention of adding a variety of requirements that door handles be inoperative when the doors are locked [20]. The agency was interested not only in preventing inadvertent door openings in crashes but also making the car more theft-proof while allowing easier access for emergency medical services after crashes. On December 28, 1967, a Notice of Proposed Rulemaking limited the new requirements to those in the standard today [23]. It became a final rule on 4/27/68 with an effective date of January 1, 1969 [24].

Thus, the regulation which is now Standard 206 gradually evolved and became stronger throughout 1962-69. As will be shown in Section 2.3, the manufacturers often anticipated the regulations and steadily improved their door locks throughout 1956-69. No single model year in the 1960's was decisive for the entire passenger car fleet.

1.3 Standard 216 - Roof Crush Resistance

Federal Motor Vehicle Safety Standard 216 "establishes strength requirements for the passenger compartment roof. The purpose of this standard is to reduce deaths and injuries due to the crushing of the roof into the passenger compartment in rollover accidents" [7]. The standard has applied to passenger cars since September 1, 1973.

The standard requires cars to meet a static strength test which involves gradual application of a load with a test device to one of the sides of a vehicle's roof, at the forward edge. "The test device is a rigid unyielding block with its lower surface formed as a flat rectangle 30 inches x 72 inches." The test device is oriented at a longitudinal forward angle of 5 degrees below the horizontal and a lateral outboard angle of 25 degrees below the horizontal, simulating the angle at which the roof might contact the ground during a typical rollover. Force is applied in a downward direction at a rate of not more than one-half inch per second (static loading). The test device "shall not move more than 5 inches ... when it is used to apply a force of 1 1/2 times the unloaded vehicle weight [curb weight] or 5,000 pounds, whichever is less."

The regulatory history of Standard 216 begins on October 13, 1967, almost 6 years before the eventual effective date. An Advance Notice of Proposed Rulemaking announced that "the administration is considering the issuance of a Federal Motor Vehicle Safety Standard specifying requirements to limit the amount of intrusion or penetration on exterior impact, including front, side, rear, and roof, of vehicle and other structures into passenger compartments of passenger cars, multipurpose passenger vehicles, trucks and buses" [22]. The agency contemplated a 1/1/73 effective date. The roof intrusion portion of the Advance Notice eventually became Standard 216. In their comments on the Advance Notice, General Motors indicated a strong preference for a static test of roof strength rather than a staged rollover or full vehicle drop test [57]. In fact, SAE Recommended Practice J374, approved December 1968, defined the static crush test envisioned by GM [71], p. 1172; it is, however, a Recommended Practice rather than a Standard, since it does not specify what is a "passing" score on the test. The predecessor of the Motor Vehicle Manufacturers Association felt that rulemaking was not justified until a cause and effect relationship was proven for roof crush and injury [61].

During 1970-71 NHTSA sponsored 10 roof crush tests of 1970 Ford Galaxies and Mavericks [4]. The tests were based on SAE Recommended Practice J374, with variations. The full sized hardtops did not perform as well as the smaller sedans. On January 6, 1971 NHTSA published a Notice of Proposed Rulemaking [25] largely based on the SAE static test, with some changes in the test device. The proposed effective date was 8/15/73, to allow leadtime for the full sized hardtops. The crush limit of 5 inches at 1.5 times the car's weight or 5000 pounds, whichever is less, is the same as the present (1989) standard. NHTSA did not agree with comments that the relationship of roof crush and injury had not been proven: the relationship is self evident and can be seen in statistical analyses. Specifically, weak roofs would negate the benefits of using safety belts. NHTSA claimed that up to 1400 persons were killed by roof contact each year [12] (an overestimate). The 5000 pound limit on applied forces was justified in the NPRM because larger cars were known to be less rollover prone. Commenting on the NPRM, Ford estimated that their Mercury 4 door hardtop would need substantial beefing up of the A pillar and other parts to meet the standard [13]. The Center for Auto Safety agreed that large 4 door hardtops were most likely to have trouble with the standard as proposed (they also urged a much stronger standard) [86]. NHTSA published their final rule on December 8, 1971, retaining the requirements in the NPRM [26].

The advance notice and relatively extended lead time gave manufacturers an opportunity to implement the standard gradually. Each year, they could make Standard 216 improvements, if necessary, on the car lines they were restyling. For example, GM noted that they had incorporated a "double steel roof" on most of their lines by 1971 [56]. But it is unclear what changes, if any, were needed for Standard 216, since small and medium size cars generally had little trouble with the Standard (as will be documented in Chapter 3).

The most significant change in roof design during the 1970's was the gradual abolition of true hardtops - cars in which the B pillar does not extend above the lower surface of the side window. They were replaced by "pillared hardtops" which have a full B pillar like a sedan, although the car is styled to conceal or disguise the pillar and look like a hardtop. The transition to pillared hardtops stretched through the entire decade. Some models shifted all at once, at the time of a major restyling; others initially introduced them as an option and took several years to make them standard [49], pp. 123-125:

	<u>All</u> Get Pillared HT	Pillared HT Becomes an <u>Option</u>
1970	Camaro, Firebird	
1971		Thunderbird, Eldorado
1972		
1973	All GM intermediates	
1974	Mustang	Full-sized & intermediate Fords Electra, Riviera, Charger
1975	Cordoba, Gran Fury, Monaco Granada, Monarch	Full-sized GM
1976	Chrysler compacts	
1977	Full-sized GM	

By 1978, genuine hardtops were available only on a few relatively low volume cars. In 1979, GM reversed the process and redesigned their sporty luxury cars as true hardtops, but all their other cars have stayed pillared since then.

Obviously, the B pillar provides additional support for the roof. Most of the weak roofs described in the literature were hardtops. Thus, a connection between Standard 216 and the shift to pillared hardtops is likely. But the literature does not explicitly state that this change was made because of Standard 216 or other safety considerations (e.g., Standard 214 - Side Door Strength). It may have been due to styling or manufacturing considerations, or all of the above. Furthermore, it is apparent that many hardtops were built after Standard 216 took effect and were able to meet or even significantly exceed the requirements. Thus, the relationship between the standard and the shift from hardtops to pillared vehicles is loose - but this shift is the main thing that happened to roof structures in the 1970's and it is one of the principal topics of the evaluation.

1.4 Background

It is best to study Standards 206 and 216 in the context of the overall trend in fatality risk of unrestrained occupants of passenger cars of model years 1963-82 in rollover crashes, for this is the type of crash in which strong roofs and better door locks are especially likely to have benefits. Standards 206 and 216, however, are not the only vehicle factors which affected fatality risk in rollover crashes during the

1963-82 period. A major task of the evaluation is to study the overall fatality trend and identify what changes are due to improved door locks and roof crush strength, as opposed to other vehicle factors.

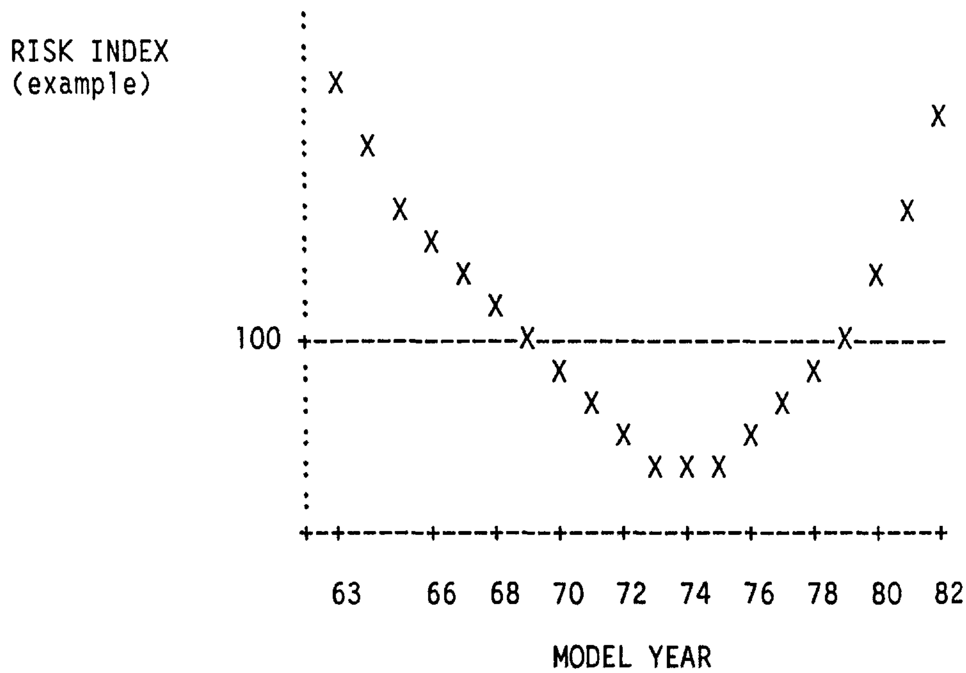
Rollover crashes are responsible for about 4,000 of the 25,000 passenger car occupant fatalities each year. They rank third after frontals and side impacts as a source of fatalities. The high number of rollover fatalities, by itself, is enough of a reason to perform an evaluation. Another characteristic of rollovers is that many of the fatal crashes do not involve great amounts of force or destruction to the car. Two thirds of the fatalities are ejected from the car, often in crashes with low damage. Since rollover fatalities appear more easily "savable" than some other types, it is especially appropriate to check if improvements in car design over the past 25 years have been effective.

On the other hand, rollover protection is more complex to evaluate than many other vehicle modifications. One reason is that there is no single dominant safety measure that was implemented to "solve the rollover problem" for the unrestrained occupant. Instead, there have been numerous changes over the years, most of them gradual. That precludes a relatively straightforward "before-after" evaluation.

Another reason is that rollovers are an area where crash avoidance and crashworthiness measures both play a major role and were often implemented simultaneously. In crashes other than rollovers, the driver is responsible for the crash in the overwhelming majority of cases and vehicle design plays a limited role in crash causation [91]. If two cars have greatly different involvement rates (e.g., Chevrolet Camaro and Caprice Wagon) it is usually because one of them has a more aggressive set of drivers. Even the most important crash avoidance improvements in braking and lighting reduce accidents by only a few percent overall [53] or up to 20 percent in narrowly defined crash situations [46], [48]. For rollovers, the vehicle is the critical factor in crash causation and is responsible for differences of 10 to 1 or more in the involvement rates of different makes and models. In response to a panic steering or braking maneuver, a car with good handling and stability may remain on the road and upright; another car might briefly run off the road but remain upright and undamaged; whereas a third car might run off the road and roll over in a ditch, possibly with serious consequences.

In nonrollover accidents, crash avoidance and crashworthiness are easy to study separately. The number of crashes per million miles (or 1000 vehicle years) is a good measure of accident risk. The number of injuries (or fatalities) per 100 crash-involved occupants is a good measure of injury risk. The two measures are essentially independent. In rollover crashes, the two measures are strongly confounded. It will be shown in this report that the cars with the highest rollover rates per million miles have the lowest fatality rates per 100 rollovers - not because they are more crashworthy, but because the fatality rate per 100 rollovers is meaningless as a measure of injury risk. The fatality rate per million miles <u>is</u> a valid measure of risk, but it incorporates both crash avoidance and crashworthiness.

Thus, it is appropriate and necessary for the evaluation to study the vehicle modifications that affect accident risk as well as those that relate to crashworthiness. Since a simple "before-after" study is impossible, the best way to track car performance in rollovers is to define the fatality <u>risk index</u> by model year, indicating the relative safety of cars during model years 1963-82:



The approach closely parallels Chapter 4 of NHTSA's evaluation of occupant protection in interior impact [47], where risk indices were developed for frontal crashes.

The first level of the analysis is to estimate the overall fatality risk index for <u>unrestrained</u> occupants of passenger cars in rollover crashes, after filtering out effects unrelated to the vehicle -

e.g., changes in the driving or roadway environment. Next, techniques are found to split the overall risk index into separate indices for crashworthiness and rollover propensity. The ultimate goal of the analysis is to identify the individual vehicle modifications that affected fatality risk during the 1963-82 period and estimate the change in fatalities for each of them. The vehicle modifications that will get the most attention are the changes in door locks and roof crush resistance associated with Standards 206 and 216.

1.5 Other vehicle modifications that affected rollover risk

The higher a car's rollover propensity, the greater the likely number of rollover fatalities. As will be discussed in Section 2.1, rollover propensity has two components, so to speak: directional stability and rollover stability. A car is directionally unstable if it tends to skid or spin out of control or is hard to steer on course. A directionally unstable car will have many off-road excursions into loose dirt, ditches, etc., where rollover is likely to occur. "Rollover stability" is the tendency of a car to remain upright given that it has come in contact with a typical off-road tripping mechanism such as loose dirt or a ditch. Short, light cars usually have less directional stability than long, heavy cars. Narrow cars have less rollover stability than wide cars. Since "small" cars are shorter, lighter and narrower than full sized cars, they tend to have lower directional and rollover stability and a substantially higher net rollover rate.

Throughout 1963-82, the sizes of passenger cars in the United

States has changed each year and rollover fatality risk has corresponding trends. Until 1974, individual makes and models tended to get heavier and/or wider each year, but that was partially offset by a shift from full-sized cars to intermediates and compacts at first and later to subcompacts [47], pp. 127 and 188-189. After 1974, individual models became shorter, lighter and narrower while the market continued to shift from large cars to imports and subcompacts. A significant increase in rollover fatalities relative to other crash modes occurred after model year 1974.

Domestic cars tended to have a stable relationship between overall size and track width during 1963-82: they got wider as they grew and narrower as they shrank. Imports did not. During the 1960's, most imports were aimed primarily at home markets, where narrow roads demanded narrow cars - e.g., track widths of 50 inches. After 1975, as sales in the United States grew, overseas manufacturers designed cars that would have more appeal here; they added 5 inches or more to track width without comparable increases in weight or wheelbases. Safety benefits can be expected for the wider cars.

Car size is not the only factor that affects rollover proneness. A car's suspension, tires and steering response can affect its directional control and stability and, as a consequence, its exposure to off-road tripping mechanisms. It is also possible that rollover stability will decrease if the suspension is designed so as to raise the car and reduce track width during cornering maneuvers, or allow the center of gravity to be displaced to the side. Section 2.2 presents evidence that the Volkswagen Beetle was exceptionally rollover prone before 1969 as a result of its suspension design.

Cars with 2 doors have significantly higher ejection risk than 4 door cars, possibly because the wider, heavier doors of a 2 door car cause a larger force to be transmitted through the door latches when the doors are impacted in a crash; also, the wider side window offers a larger portal for ejection [52], pp. 139-146. As a result, 2 door cars have a higher fatality risk in rollovers than 4 door cars. The mix of 2 and 4 door cars changed steadily during 1963-82, in response to consumer demand. In model year 1963, only 43 percent of sales were 2 door cars. As baby boomers entered the driving population, they demanded 2 door cars; by 1974-75 2 door cars accounted for 67 percent of sales. When the baby boomers started having families, demand shifted away from 2 door cars, dropping to 45 percent of sales in 1982. As the mix of 2 and 4 door cars changes, the rollover fatality risk can also be expected to change.

Whereas side doors and windows are the principal ejection routes in rollover crashes, a smaller number of occupants are ejected through the windshield portal, especially after the windshield has been separated from the bond. Adhesive bonding of the windshield, introduced by domestic manufacturers during 1963-78 and somewhat later by overseas manufacturers (in response to Standard 212) significantly reduced ejection through the windshield portal [50].

Although the first goal of the evaluation is to track the overall fatality risk index in rollovers by model year, the ultimate objective is to estimate the effect on fatalities of the individual vehicle modifications described above - and to check if there are any other significant changes in the fatality index that cannot be attributed to the modifications described above. In chronological order, the vehicle changes expected to have affected rollover risk during 1963-82 are:

Vehicle Modification	Date
1. Improved door locks (Standard 206)	1963-69
2. Shift from 4 door to 2 door cars	1963-74
3. Adhesive bonding of the windshield	1963-82
4. Improved suspension for Volkswagen	1967-69
5. Shift to imported or subcompact cars	1970-82
6. Stop production of true hardtops (Std. 216)	1971-77
7. Downsizing of existing car lines	1975-82
8. Shift from 2 door back to 4 door cars	1976-82
9. Wider tracks for some imported cars	1977-82

The evaluation will devote special attention to the effect of roof crush strength and the elimination of hardtops, because less is known here than for the other changes listed above. The analysis will not be limited to a study of the trend in fatality risk. In addition, the actual roof crush performance of cars will be tracked for the 1963-82 period, based on laboratory test results (Chapter 3) and highway accidents (Chapter 4).

1.6 Current NHTSA activities

Despite the benefits associated with improved door locks and roof crush resistance, rollover crashes continue to account for a high percentage of fatalities in passenger cars, light trucks and utility vehicles - close to 7,000 deaths per year. The growing popularity of light utility vehicles has focused attention on the problem. The major advances in testing, simulation and biomechanics during the past 10 years have encouraged NHTSA to undertake a comprehensive research and rulemaking program to find ways to reduce the number of rollover crashes and to protect occupants in those crashes.

The agency is developing new accident data bases to improve understanding of the causes of actual rollover crashes - driver maneuvers, the highway and off-road environment, and vehicle response [38]. Several mathematical and computer models are being developed to simulate vehicle dynamics in rollovers and analyze the sensitivity of a vehicle's rollover propensity to changes in design - also, occupant kinematics and injury potential [67]. Vehicle testing and evaluation activities include staged rollover crashes for validating the simulation models and preliminary design of a "standard" rollover test facility.

Occupant ejection is still a major cause of fatalities in potentially survivable crashes. NHTSA is performing staged crashes and developing computer simulations to study the dynamics of occupant ejection. The agency is studying the strength of current door lock systems and developing glass-plastic side windows designed to reduce ejection risk [5], [10].

The agency also has regulatory programs underway to address the issues of rollover avoidance and occupant protection. In September 1988, NHTSA granted a petition [79] by Consumers Union "to initiate rulemaking proceedings to establish a minimum standard to protect against unreasonable risk of rollover [29]." The NPRM to upgrade Standard 214, the side impact protection standard, includes a requirement that the doors remain closed during the dynamic side impact test [81], pp. IV-37 - IV-41. The objective is to reduce the risk of occupant ejection through open doors in side impacts but it might also have benefits in other crash modes, including rollovers.

CHAPTER 2

EARLIER STUDIES OF ROLLOVER PROPENSITY AND FATALITY RISK

Many statistical, experimental and engineering studies of rollover crashes have been published. The literature provides convincing evidence of a relationship between car size and rollover propensity. It clearly shows that improvements to door locks during the 1960's improved passenger compartment integrity in crashes. The literature does not provide definitive results on the effect of roof strength, but most studies infer that it is a minor factor in fatality risk. There are some detailed descriptive studies of rollover crashes.

2.1 Car size and rollover propensity

Thousands of years before the invention of the automobile, people were aware that narrow, top-heavy structures tip over more easily than wide, low ones. Hundreds of years ago, scientists developed mathematical formulas for the force needed to tip over a structure. In an automotive context, as early as 1962 Stonex defined the "stability factor" of a car as half the track width divided by the height of the center of gravity [89]. He noted that the stability factor for domestic cars had increased steadily from World War 2 till the early 1960's.

In 1968, Garrett performed an early but authoritative study of the relationship of car size to rollover propensity [33]. Using Automotive Crash Injury Research (ACIR) data from New Mexico and Utah, he defined the rollover rate of a car to be the ratio of principal rollovers to other single vehicle crashes. His idea is that rollovers and other single vehicle crashes typically involve about the same type of driver behavior - i.e., losing control of the car and running off the road. The other single vehicle crashes act as a sort of control group and cancel out biases due to differences in driving exposure or aggressiveness. The approach is especially appropriate with ACIR data, which are not a random sample of accidents and have no underlying exposure data base. But it works well with other data and has been used in nearly all subsequent studies of rollover propensity including the analyses of this report.

Garrett looked at rollover rates of cars from the early 1950's through model year 1967. He made reference to the "stability factor" and clearly would have liked to use it as the independent variable. Since measurements of the height of the center of gravity were not available, he used the curb weight and overall height of the car as surrogates for c.g. height. The same technique is used in Chapters 4-7 of this report for cars built 20 years later. He performed a regression of the rollover rate by track width, curb weight and height. "The data indicate that there is a strong correlation between rollover frequency and vehicle dimensions: rollover increases as car size shifts from heavy, wide track, low vehicles to light, narrow track, high cars. Car weight and track width appear to have the greatest influence on vehicle overturn."

Jones published a combined engineering and statistical study of rollover propensity in 1973 [45]. He calculates the "minimum lateral velocity needed to overturn a car against a 6 inch kerb" - an important quantity since most passenger car rollovers begin when a car is tripped by a rise or drop in the terrain. The formula involves the car's track width, c.g. height and mass, among other parameters. It is not a simple linear formula; also, the parameters within the formula are themselves highly intercorrelated. But as a general rule, the higher the track width and the mass and the lower the c.g. height, the higher a lateral velocity it takes to trip the car. Jones measured the c.g. heights and overturning velocities for 19 models sold in Britain. He calculated the rollover propensity for those models in rural British accident data for 1969-70 - i.e., the ratio of rollovers to other single vehicle crashes. Rollover propensity had a significant negative correlation with the stability factor and even more so with the minimum lateral velocity needed to overturn the car.

Griffin, in 1981 was the first to analyze rollover rates on a large domestic State accident file: 1980 Texas data [36]. He was also the first to use logistic regression - i.e., the dependent variable is the log of the odds ratio of rollovers to other single vehicle crashes. This variable has excellent linear correlation with car size variables and little correlation with the residual error, which is exactly what is desired for a regression. Griffin's only independent variables are curb weight and road type. He found strong correlations with each. Chapter 5 of this report performs logistic regressions with additional independent variables and a much expanded Texas data set.

Harwin and Brewer have performed the most thorough analyses to date (1989) of rollover propensity vs. the stability factor [37]. They obtained measurements of the stability factor for 20 models of passenger cars and 8 utility vehicles. State accident data from Texas (1984-85), Maryland (1984-85) and Washington (1983-85) were acquired through NHTSA's CARDfile data base. In their linear regressions, the dependent variable is the percentage of single vehicle crashes which are rollovers. The dependent variable has a strong negative correlation with the stability factor. Other independent variables, describing the driver and the roadway, are not nearly as important as the stability factor in multiple regressions.

Malliaris, Nicholson, Hedlund and Scheiner of NHTSA explored the relationship between car size and propensity of various types of crash involvement in a 1983 paper [60]. Like other authors, they found a strong negative correlation between rollover risk and curb weight. An important concept suggested by this paper is that rollover risk has two components, so to speak: directional stability and rollover stability. A car is directionally unstable if it tends to skid or spin out of control or is hard to steer on course. A directionally unstable car will have many off-road excursions into loose dirt, ditches, etc., where rollover is likely to occur. "Rollover stability" is the tendency of a car to remain upright given that it has come in contact with a tripping mechanism such as loose dirt or a ditch. Malliaris et al found that lighter cars have lower directional and rollover stability than heavy cars: they have a greater tendency to skid or spin out of control (as evidenced by an overrepresentation of side impacts with fixed objects relative to frontals with fixed objects) and a greater tendency to roll over given an out-of-control, off-road excursion (as evidenced by an overrepresentation of rollovers even relative to side impacts with fixed objects). Thus, lighter cars have a much higher net rollover risk than heavy ones.

NHTSA's 1988 Technical Evaluation [90] of Congressman [now Senator] Timothy Wirth's petition further explores the issues raised by Malliaris et al. Wirth petitioned that rollover propensity of light duty vehicles be limited by establishing a minimum requirement for stability factor, preferably 1.2. The gist of NHTSA's response is that stability factor is not the sole predictor of rollover risk. A big part of NHTSA's argument is that rollover risk is a compound of "directional stability" and "rollover stability." The stability factor is highly related to "rollover stability" but not necessarily to "directional stability." A vehicle might score well on the stability factor but because of its low directional stability be prone to running off the road and into terrain that prompts rollovers. Conversely, a vehicle with relatively poor stability factor might have low rollover rates because it hugs the road and stays out of "tripped rollover" terrain.

NHTSA states that a number of vehicle size parameters, especially wheelbase, are related to directional stability. The longer the wheelbase, the easier it is to retain directional control. NHTSA demonstrates excellent correlations between wheelbase and rollover risk, in one of the data files even exceeding the correlation of stability factor and rollover risk. NHTSA acknowledges that firm conclusions are hard to draw because wheelbase and stability factor are themselves highly intercorrelated (most "big" cars are high on both); nevertheless, the issue of directional stability must be considered as a factor in rollover risk.

During 1988-89 Partyka and Boehly of NHTSA studied the correlation of car weight and fatality risk in various crash modes [77]. While their paper concentrates on single vehicle nonrollover crashes, it also presents rollover fatality rates of cars less than 10 years old on 1978-87 FARS files [16], [17]. They performed a regression of the rollover fatality rate per 100,000 vehicle years by car weight and obtained the statistical relationship

$$\text{fatality rate} = 8.01 - .00123 \text{ car weight}$$

The paper does not address whether this is a "cause and effect" relationship or a result of the strong correlation of car weight with other parameters such as track width, wheelbase or stability factor. Although Partyka and Boehly do not suggest using the formula this way, it will yield a fatality rate prediction if the average weight, by model year, is substituted for "car weight." The formula suggests that a fleet consisting entirely of 1982 models, which averaged 2680 pounds, would have had a fatality rate of 4.71 during calendar years 1978-87. A fleet of pre-downsized 1975 models, averaging 3709 pounds, would have had a fatality rate of 3.45. The formula suggests, in other words, that the shift to subcompacts and imports, downsizing, etc. between model years 1975 and 1982 is associated with a 37 percent increase in the rollover fatality rate. That matches the findings in Table 8-3 of this report, which were derived by a quite different data set and analysis procedure (4000 fatalities in model year 1982 and 2927 in 1975, also a 37 percent increase).

2.2 Other factors which affect rollover propensity

During the mid 1960's, as large numbers of Volkswagens were sold in the United States, evidence mounted that the cars were overinvolved in rollover crashes. For example, Garrett and Stern reported in 1968 that 28 percent of the VW crashes on the ACIR file are principal rollovers without any collision, as opposed to just 10 percent of large American cars [34]. Researchers wondered whether this was merely because Volkswagens are significantly narrower and more top heavy than American cars of the 1960's or if additional factors increased rollover propensity even further.

A detailed engineering study of the Volkswagen [11] identified three factors that made the Beetle more rollover prone than other cars of its size and weight. The most important is the torsion bar rear swing axle suspension. During cornering, any car will have a tendency for the rear outside portion to lift. With an ideal suspension, the wheels stay more or less flat on the road. With the swing axle suspension, the lifting of the car causes the axle to swing down and in underneath the car, so the wheel tilts outward at the top (positive camber). In effect, the track width becomes narrower and the center of gravity higher (lower stability factor). "The technical term for this is 'jacking.' The jacking effect is self promoting since the higher the rear end is lifted, the more leverage the outside wheel and axle have" [11], p. 25. The swing axle suspension was eventually replaced by a system with double universal joints which largely eliminated the problem of jacking and camber change; the improvement was made in model year 1968 in Beetles with semiautomatic transmission and in 1969 on all other Beetles.

The second factor is the absence of "safety humps" on the wheel rims. During cornering, it became possible for side loads on the tire "to pull the <u>tire</u> into the center of the <u>wheel</u>, causing an 'airout.' If, for instance, a car is turning left and the right tires suddenly air out, the car will fall suddenly over toward its right side and this may induce rollover" [11], p.30. In mid 1968, Volkswagen received wheel rims with safety humps that resist tire separation from rims.

Finally, the concentration of the vehicle mass toward the rear of the car, as would be the case in any rear engine car, is a cause of low stability during steering. Loss of steering control might result in either a rollover or an impact with a fixed object, depending on the roadway environment. Since "rollover proneness" is measured in most studies as a ratio of rollovers to fixed object impacts, this last factor might not show up in the analysis.

Since improvements to axles and wheels were made gradually in 1967-69, a reduction in rollover proneness should be expected at that time. Indeed a 1973 study by Garrett [32], following up on his 1968 report cited above [34], found that the frequency of rollover without collision decreased from 25 percent of ACIR cases in the 1960-67 Volkswagens to 16 percent in the 1968-70 Volkswagens.

NHTSA's Technical Evaluation of the Wirth petition notes that vehicles' chassis and suspension design, to the extent that they affect directional control and stability, have an influence on rollover risk.

2.3 Effect of door lock improvements

One of the earliest and most important safety improvements of the postwar era is the introduction of safety door latches on domestic cars in 1955-56. Throughout the 1960's manufacturers made repeated incremental improvements to door locks. Garrett tracked the history of the modifications and analyzed their effectiveness with ACIR data. In a 1964 report, Garrett found that doors opened in 42 percent of the pre 1956 domestic models involved in crashes on ACIR, but just 27 percent of 1956-62 model cars and 23 percent of 1963's [31]. The differences are statistically significant. He noted that GM made incremental improvements on their 1956 design in 1963 and Ford, in 1962 or 1963, depending on the model of car. The Chrysler design of 1956 was already as effective as Ford and GM's 1963 designs.

Garrett followed up with a 1969 study which covers all the years of ACIR data through 1968 (the effective date of Standard 206) [30]. It is limited to the big 3 domestic manufacturers. He demonstrates that changes in latch design were almost a continuous process in the 1960's. By manufacturers, the model years of latch redesign were:

Chrysler	1964, 67, 68
Ford	1962, 63, 66, 67
GM	1963, 64, 67, 68

His principal finding is that the percent of ACIR crashes (standardized by accident type and impact speed) in which doors opened decreased steadily during model years 1956-68:

Model Year	Percent where Doors Opened
Pre 1956	43
1956-62	28
1962-63	23
1964	17
1965-66	17
1967-68	12

The frequency of door opening in the 1967-68 models is nearly the same in Chrysler, Ford and GM cars. There were no significant differences among the domestic manufacturers after 1963. The main causes of door opening in crashes, according to Garrett, are latch damage, inadvertent opening of the doors by occupants and latch components pulling free of the door or post. Hinge damage is much rarer than latch damage, except in severe crashes with vehicle deformation near the hinges. Ford and GM cars may have experienced a major reduction in hinge damage circa 1967, while Chrysler always had low rates of hinge damage.

Volkswagen did not introduce the safety door latch until mid 1965 [11]. In 1967 they improved it with an interlocking system. Garrett's 1973 study of Volkswagen [32] furnishes ACIR data on door opening which complements his earlier analysis for domestic cars. The frequency of door opening decreased from 37 percent of ACIR cases in the

1960-67 Volkswagens to 13 percent in the 1968-70 Volkswagens. The frequency of ejection in principal rollovers decreased from 23 percent to 11 percent. The proportion of ejections in which the door was the ejection portal (rollovers plus other crash modes) decreased from 75 percent to 50 percent. "These shifts resulted in a distribution of injury causes that was not significantly different among the occupants of 1968-70 models of Volkswagens, [other] foreign sedans or light U.S. cars."

The trend toward fewer door ejections may have continued beyond 1968. Huelke, Compton and Studer looked at ejection portals in rollover crashes [42], based on National Crash Severity Study (NCSS) data [76]. They found that, by the late 1970's, the side window had replaced the door as the predominant ejection portal. Bertram and O'Day analyzed the same data and found the side window to be especially prevalent as an ejection portal in small cars [3].

More recently, Shams, Nguyen and Chi analyzed the relationship between door latch strength and ejection risk [83]. Their 1986 study, performed under contract to NHTSA, is cross sectional rather than historical. The authors computed ejection fatality rates per million exposure years, by make/model, for model year 1981-83 cars, light trucks and utility vehicles, based on FARS [16], [17] and Polk [70] data. They measured the latch and hinge strength of the doors of 24 model year 1983 cars by placing them in the Standard 206 text fixture and increasing the loads - beyond the Standards 206 requirements - until failure occurred. They performed a correlation analysis and found a strong inverse relationship between latch strength and ejection risk.

Willke et al of NHTSA published a detailed review of this study, pointing out a number of flaws [92]. It was found that strength test results are extremely sensitive to certain parameters in the test setup and that Shams et al did not keep these parameters constant from test to test. NHTSA performed a new series of tests with tight control of the test parameters; these corrected strength measurements had much lower correlation with ejection rates than before. In addition, Willke et al found some correlation between latch strength and car size. The cars with stronger latches may have lower ejection risk, in part, because their larger size makes them less rollover prone. The agency is collecting additional data on the subject and will continue to research it.

2.4 Relative risk of ejected and nonejected occupants

Researchers have long wondered how much ejection increases injury or fatality risk - e.g., given an ejected fatality, what would have been the probability of survival if the person had remained within the car, in that same crash. The issue is relevant for several reasons. If ejection greatly increases fatality risk, remedies to prevent ejection, such as improved door locks, are obviously valuable. But if the person would have died anyway within the car, the remedies are of little value. If ejection greatly increases fatality risk, it becomes reasonable to analyze ejection and nonejection fatalities as virtually separate classes of accidents - i.e., the ejection fatalities occur to a large extent in crashes that would have been nondangerous without the ejection. If not, any reduction of ejections would be accompanied by an obvious increase in nonejection fatalities and it would be wrong to analyze the two types independently.

At first, researchers simply compared the overall injury rates for ejected and nonejected persons and found ratios of 20 to 1 or more. As early as 1974, Kahane attempted to control for preimpact speed in rural Pennsylvania data and, after adjusting the data, found ejectees 3.5 times as likely to be killed or seriously injured as nonejectees [54], p. 35. A much better way to control the data for crash severity is to perform double pair comparison analysis [14]. Sikora used 1982-85 FARS data and concluded that ejection increases the risk of an unrestrained driver being killed by a factor of 3.94 and for a right front passenger by 2.61 [85]. More recently, Evans and Frick calculated the increase in fatality risk to be 3.8 for all seat positions combined [15].

An entirely different approach is to look at the injuries and contact points of ejection fatalities and estimate what proportion of them received fatal lesions while they were still within the car. This method is far less reliable because contact points are hard to document, especially those exterior to the passenger compartment. It is also hard to judge which combination of injuries "caused" the fatality. Huelke, Compton and Studer looked at occupant contacts in rollover crashes in NCSS with <u>known</u> contact points [42]. They found that 58 percent of ejectees get their most serious injuries from contacts inside the car - i.e., ejection increased the fatality risk by only 100/58 = 1.72. That is a serious underestimate because contact points subsequent to the ejection are rarely found in the after the fact investigations of data systems such as NCSS or NASS. Since most of the known contact points are within the car, it gives the false impression that a majority of ejectees would have died even if they had stayed within the car. A slightly more useful estimate was obtained by Kahane with mostly Multidisciplinary Accident Investigation (MDAI) data [9], [65], which are far less prone to missing contact points than NCSS; the MDAI data suggest that 43 percent of ejection fatalities, for portals other than the windshield, received life threatening injuries within the car [50], p. 162. In other words, ejection increases fatality risk by 100/43 = 2.33.

The estimates based on double pair comparison are far more reliable. Since ejectees are 3.8 times worse off than if they hadn't been ejected, a measure that reduces ejection has a chance of saving 2.8/3.8 = 74 percent of the ejectees. Also, most of the crashes with fatal ejection would not have been dangerous for persons who stay within the car, so it is reasonable to perform separate analyses for the ejection and nonejection fatalities.

2.5 Effect of roof crush strength

The literature includes several studies of roof performance in rollovers, but few definitive conclusions because of the complexity of the subject. With in-depth data files it is possible to estimate the proportion of serious injuries which involve contact with the roof, but not so easy to judge how that proportion would vary as a function of roof strength. A number of studies have shown that rollovers with more roof crush have higher injury rates, but it is not clear that the first is causing the second.

An early statistical analysis cited by NHTSA in support of its Standard 216 rulemaking claims that 1400 persons were killed by roof contact out of a total of 12,600 rollover fatalities in 1969 [12]. The estimate was made before FARS or any other nationally representative fatality data base existed. The proportion of fatalities involving roof contact is fairly accurate but the total number of rollover fatalities is quite overstated.

Mackay and Tampen published "Field Studies of Rollover Performance" in 1970 [59]. Not much of the report deals with roof crush, but the authors did note that the most common location of maximum crush is in the front of the roof, midway between the left and right sides of the car. They recommended a roof crush standard which gives the regulator the option to apply the load to any part of the roof, including the middle.

Three major statistical or laboratory studies were published during the early 1970's, when Standard 216 was promulgated. Each downplayed the potential benefits of the roof crush standard. Hight, Siegel and Brooks analyzed 139 MDAI rollover cases from California [40]. A principal finding is that "A low-profile heavy United States [true hardtop] generally sustains more roof crush than a lighter import vehicle with A-, B-, and C-pillars." Lower, wider cars are more susceptible to roof crush because the car vaults after it goes on its side and then collapses onto its roof as it goes upside down. The dropping of the car puts dynamic force on the roof. In narrower cars, the vaulting and collapsing is less pronounced during the roll. Another important finding is that, out of 37 fatalities, only 2 were nonejectees in pure rollovers without another impact; 24 were ejectees and 11 were in multiple impacts. After reviewing injury causation in the crashes, they concluded that "injury severity was not a direct function of roof crush."

Huelke, Marsh and Sherman reported on a different MDAI sample of 294 rollovers [44]. They found a weak but consistent association between roof crush and injury severity as measured by the Abbreviated Injury Scale (AIS) [1]:

Inches of Roof Crush	Average AIS
0	1.7
1-6	1.6
7-12	2.3
13-24	2.6
25+	3.9

Roof crush appears to have a strong association with injury severity only in those extreme cases with more than 25 inches of crush. Elsewhere, the relationship is weak: the association of rollover injury and <u>frontal</u> inches of crush is nearly as strong. In fact, the authors consider it possible that roof crush may even be beneficial in keeping the door jammed shut and/or reducing the size of the window ejection portal. They conclude that "the roof crush standard would not reduce the interior impact hazard for unbelted occupants." Their conclusion appears to apply primarily to survivable crashes without excessive roof crush.

Stone performed staged rollover tests with production cars and cars with modified roof structures (stronger and weaker) [88]. Increased roof strength did not significantly increase the safety of the passenger compartment environment; if anything, the cars with strengthened roofs rolled over more times on the average. This laboratory study did not include an extremely severe rollover condition or an exceptionally weak roof.

In 1983, 9 years after Standard 216 took effect, Huelke and Compton looked at rollover injuries in NCSS [41]. Only 15 percent of severe to fatal (AIS 3-6) injuries in rollovers are due to contact with the roof or other structures at the top of the car. Huelke reiterated his earlier view that "roof deformation is not causally related to injury severity."

Plastiras et al. analyzed the relationship between roof crush strength and injury risk [80]. Their 1985 study uses a cross sectional approach similar to Shams' work on door latches and ejection risk (see Section 2.3). They picked 12 subcompact cars of model years 1974-78 and computed injury rates per 100 rollovers for these specific models and model years in 1975-82 Washington State accident data. Roof crush strength measurements for the 12 cars was based on performance in Standard 216 compliance tests - i.e., the inches of crush needed to meet the minimum strength requirement.

The linear correlation between the injury rate and the crush on the Standard 216 test is .1, which is nowhere near statistical significance. The authors conclude that there is "no apparent relationship between roof crush performance, as measured by the roof crush test specified in FMVSS 216, and occupant protection, as measured by injury rates reported in the Washington State accident data base." Although intrinsically similar to the Shams' analysis, this study has limitations which virtually guarantee that no significant effects would be found. The Washington State data base, unlike FARS, will not have large numbers of injury producing rollovers for meaningful injury rates on individual models and model years, except in a few cases. All of the subcompact cars tested under Standard 216 have reasonably strong roofs. These cars are likely to perform about equally well in low severity rollovers, the type that predominate on a State file which consists mostly of nonfatal accidents. For this approach to have a chance of success, it should use FARS data and concentrate on large cars, including those with the weakest roofs.

2.6 Descriptive studies of rollovers

Although this evaluation does not include detailed analyses of specific types or causes of rollover accidents and injuries, a summary of findings in descriptive studies is useful as background. McGuigan and Bondy reviewed NCSS plus the FARS data available in 1980 [63]. They found that 86 percent of rollovers are single vehicle crashes; 72 percent of rollovers begin off the roadway. While 86 percent of the cars had lost traction and were sliding prior to the rollover, only 30 percent were spinning - a sliding car may be easier to trip than a spinning one. The vast majority of these cars were sliding sideways with, perhaps, a slight forward movement. Doors opened in 23 percent of rollover crashes, 27 percent if there was an impact prior to the rollover. Interestingly, though, the door is the ejection portal for only 23 percent of rollover ejectees, as opposed to 63 percent in side impacts (these are post-Standard 206 cars). The serious injury rate per 100 rollover crashes seems best correlated with two "severity" measures, the amount of roof crush and the number of quarter turns. But these are not necessarily cause and effect relationships; deep crush and many rolls might just be signs of crash severity, not the injury mechanisms.

McGuigan wrote another paper attempting to define a "severity" measure for rollovers analogous, say, to Delta V in planar crashes [62]. That is a difficult task. Roof crush and the number of quarter turns seem to have a relationship with the intrinsic "severity" of a crash, but they are less than ideal measures, since different cars are likely to have different amounts of crush and turns given the same intrinsic "input" crash conditions (e.g., sliding sideways into a 6 inch curb at 30 mph). For pure rollovers, McGuigan finds the best predictor of injury severity per 100 crashes is a combination of roof crush and the number of turns. For rollovers that come after a planar impact with a vehicle or object, the Delta V for that impact is the best predictor, even when the injuries are primarily due to the rollover event.

Najjar uses a different approach to define a "severe" rollover - viz., he bases it on the outcome (the injuries) [66]. Crashes that include a planar impact and a rollover often have frontal or side contacts as the source of most severe injuries; they ought not be included among "severe rollovers." Instead a severe rollover is defined as one with severe to fatal injury (AIS 3-6) from roof contact or ejection, a group which includes half of the pure rollovers and a quarter of the impact plus rollover crashes with severe to fatal injuries. These severe rollovers have a median of 4 quarter turns, often have extensive roof crush, and usually involve a car sliding (93%) sideways (89%) off the road (81%) into sod or dirt (72%).

In NHTSA's Crash Avoidance Rollover Study, Harwin and Emery noticed the confounding of rollover propensity and the injury rate per 100 rollovers [38]. Cars that tend to roll over easily (small, narrow cars) do so in crashes of intrinsically low severity, such as sliding sideways into a curb at 15 mph. These rollovers have low injury rates. Larger cars would not roll over at all in those circumstances; when they do roll over it's a severe crash likely to result in injuries. As a result, the injury rate per 100 rollovers is a meaningless measure of risk when cars of substantially different sizes are being compared. A major task in this evaluation is finding a better measure of injury risk.

CHAPTER 3

ROOF CRUSH STRENGTH BY MODEL YEAR, BASED ON LABORATORY TESTS

The compliance test for Standard 216 involves gradually loading the roof close to the A pillar and measuring the amount of crush that occurs at a load of 150 percent of the weight of the car or 5000 pounds, whatever is less. One way to compare roof crush strength across model years is by analyzing the results of Standard 216 tests. Since the standard took effect in August 1973, NHTSA has sponsored 108 compliance tests of new cars of model years 1974-85. In 1988, NHTSA sponsored 20 additional tests of used cars of model years 1964-74. Out of the 128 cars tested, 126 met the minimum requirements of Standard 216, including all the pre-Standard cars. Two cars did not meet the minimum requirement and another 11 or so passed by a narrow margin (only one of the failures was in a compliance test and the manufacturer provided the certification information required by NHTSA). Six of these 13 were full-sized pre-1975 hardtops. When manufacturers stopped building true hardtops in the mid 1970's, they eliminated many of the weakest performers. A statistical analysis of the crush measurements shows that, other than the elimination of large hardtops, roof strength changed little during the 1964-85 period. The Standard 216 compliance test is just one way to measure roof strength and the results of this chapter need to be reviewed in combination with Chapter 4, which examines roof damage in actual rollover crashes.

3.1 Compliance tests for Standard 216

The compliance test for the roof crush resistance standard [7] involves applying a load with a test device to "either side of the forward edge of a vehicle's roof. Both the left and right front portions of the vehicle's roof structure shall be capable of meeting the requirements, but a particular vehicle need not meet further requirements after being tested at one location. The test device is a rigid unyielding block with its lower surface formed as a flat rectangle 30 inches x 72 inches." The vehicle is fixed rigidly in position with "the sills or the chassis frame ... on a rigid horizontal surface." Windows are closed and doors are closed and locked: whatever they contribute to roof strength is allowed in the test. The test device is oriented at a longitudinal forward angle of 5 degrees below the horizontal and a lateral outboard angle of 25 degrees below the horizontal, simulating the angle at which the roof might contact the ground during a typical rollover. Force is applied "in a downward direction perpendicular to the lower surface of the test device at a rate of not more than one-half inch per second" (static loading). The test device "shall not move more than 5 inches ... when it is used to apply a force of 1 1/2 times the unloaded vehicle weight [curb weight] or 5,000 pounds, whichever is less."

Compliance test procedures are specified in more detail by the NHTSA Office of Vehicle Safety Compliance in document TP216-03 [58], which was published in 1986 and includes minor changes of earlier test procedures. Four items in the document deserve mention since they add to the information generated during the compliance test:

> The curb weight of the vehicle shall be measured and recorded.
>
> The laboratory shall produce a graphic display of load versus displacement.

The laboratory shall document the amount of roof crush at the minimum level of force required by the standard.

The test laboratory is expected to go somewhat beyond the minimum force level required to meet the standard and to document the amount of roof crush that occurs at this "maximum" force level. But TP216-03 is not specific on how high the maximum force ought to be.

Thus, a compliance test report includes 5 items of numerical information:

(1) Curb weight

(2) "Minimum" crush strength, which is 1 1/2 times curb weight or 5000 pounds, whatever is smaller

(3) "Minimum" roof crush, the amount of deflection at the minimum crush strength

(4) "Maximum" crush strength, which is some level of force higher than the minimum crush strength

(5) "Maximum" roof crush, the amount of deflection at the maximum crush strength

As a special case, if a car fails to meet the Standard 216 requirement with less than 5 inches of crush, the laboratory may stop the test at that point, listing 5 inches as both the "minimum" and "maximum" roof crush and the level of force attained at 5 inches as both the "minimum" and "maximum" crush strength.

Compliance test results for 108 cars of model years 1974-85 are documented in Appendix A. Only one car failed NHTSA's compliance test: the 1974 Chevrolet Caprice 4 door hardtop. The agency followed its usual investigation procedure after obtaining the test results, issuing Certification Information Request No. 1168 to GM. The manufacturer certified that 7 similar hardtops had been tested and met the requirements (with 3.8-4.7 inches of crush). GM attributed the compliance test results to the high temperature at the time of NHTSA's test. The agency closed its investigation after receiving GM's certification information.

The distribution of the 108 cars on certain key variables is as follows:

Model Year

20	MY 74	24	MY 83
15	MY 75	20	MY 84
10	MY 76	9	MY 85
10	MY 78		

Manufacturer

29	General Motors	5	Volkswagen
19	Ford	8	Other European nameplates
17	Chrysler	26	Japanese nameplates
4	American Motors		

Market class

12	Full-sized cars	4	Sporty domestic cars
17	Intermediates	61	Subcompacts and imports
14	Compacts		

Body style

10	True hardtops	87	Sedans or coupes
11	Station wagons		

The key variables, however, are not uncorrelated. In the later model years, small and imported cars account for the majority of the tests, even beyond their market share. That is in accord with NHTSA's compliance test strategy, where the emphasis is on selecting previously untested models rather than making selections proportional to market share. But in the statistical analysis of this chapter, it creates a bias in favor of the later model years, since smaller cars generally have less roof crush.

3.2 Additional tests of older cars

Compliance tests, of course, are only performed for post-standard cars. In order to gauge the effect of Standard 216 and, more generally, to obtain a record of roof strength for the entire 1964-85 period, NHTSA sponsored tests of pre-Standard 216 cars [55], using the procedure defined in document TP216-03 [58]. There were, however, some departures from the compliance test procedure. Most important, while compliance tests are performed on new cars, it was necessary here to test used cars, some as much as 24 years old at the time of their testing in 1988, which raises the concern that corrosion or other deterioration could have weakened the roof structures. Three strategies were employed to minimize the problem. The test vehicles were obtained in the San Bernardino/Riverside metropolitan area, where the mild and dry climate keeps corrosion to a minimum. The contractor only used vehicles whose roof structure was intact - including the windshield, side window and the door on the side of the car that was tested; roof structures were inspected and also tested with magnets for nonmetallic filler materials. Finally, 6 of the 20 tests were performed on post-Standard 216 cars more or less identical to 6 of the cars that had been compliance tested, allowing a direct comparison of the performance of new and used cars.

There were a few other deviations from the compliance test procedure. According to TP216-03, curb weight is measured by actually weighing the car with fluids. The cars for these tests were acquired from salvage yards and had often been stripped of engines, tires, seats, hoods, or other resalable items (but the roof and its supporting structures were intact). Curb weight had to be obtained from Automotive News Almanacs. TP216-03 allows testing to stop if 5 inches of crush are achieved before the minimum required crush strength is reached. Anticipating that at least some of the pre-standard cars might have trouble meeting the standard, NHTSA specified that tests should go beyond 5 inches and even as far as 12 inches until the "minimum required" force was reached. The contractor's test device had a stroke of 6 inches. In the one test where the minimum force was not reached in the first 6 inches, the contractor fully stroked the test device, unloaded, added an extension to the device and reloaded.

The original test matrix was based on a selection of 7 model year 1974-75 cars which were actually compliance tested when new and represented a wide range of car sizes and manufacturers:

1974 Chevrolet Caprice 4 door hardtop
1974 Chevrolet Malibu 2 door coupe
1974 Ford Galaxie 500 2 door hardtop
1974 Ford Mustang II 2 door coupe
1975 Plymouth Valiant Scamp 2 door hardtop
1974 Toyota Corolla 2 door coupe
1975 Volkswagen Beetle 2 door coupe

A duplicate or near duplicate of each of those vehicles was to be acquired and tested, allowing a performance comparison for new and old cars. The original test matrix included 7 cars of the same make, model and body style, but of model year 1969 or 1970: in all cases except the VW Beetle, there was a major restyling somewhere between 1970 and 1974. (The "same body style" rule was waived for the Malibu and Mustang, since true hardtops were available in 1970 but not in 1974.) Finally, the matrix included 6 matching cars of model year 1965 or 1966 - all except the Toyota Corolla, which was not sold in the United States back then.

In many cases it was possible to adhere exactly to the original test matrix, but sometimes the exact make, model and model year could not be found with the roof structure intact. In most cases it was possible to find a car of essentially the same design by allowing substitutions in the model (e.g., Dart for Valiant), model year (if no major restyling occurred between the original and the substitute model year) or number of doors. Two vehicles, the 1975 Beetle and the 1970 Toyota had not yet been located late in the project and it was felt appropriate to drop them from the test matrix: the 1975 Beetle (a repeat of a model that had been compliance tested), because it had become evident that there were no great differences between new and used cars; the Toyota, because it had become evident that small cars were having no difficulty meeting the standard. A 1969 Pontiac Grand Prix hardtop and a 1972 Chevrolet Biscayne sedan were tested instead. That would allow a comparison with the 1969 Chevrolet Chevelle sedan and 1974 Chevrolet Caprice hardtop already in the matrix, shedding additional light on the difference between hardtops and sedans.

Table 3-1 presents the test results in the order that the tests were run. All of the pre-Standard 216 cars met the minimum requirements of Standard 216 in that they had "Minimum Roof Crush" less than 5 inches. The best performer was the 1964 Dodge Dart which achieved the required force level at 0.9 inches of crush. The 1974 Chevrolet Impala 4 door hardtop had the weakest roof, achieving the required force level only at 9.5 inches of crush, replicating the compliance test result for this car.

TABLE 3-1

TEST RESULTS: ROOF CRUSH RESISTANCE OF USED CARS

Test No.	MY	Make	Model	N of Doors/ Bodytp*	Min Crush Wt.	Min Roof Crush	Max Crush Wt.	Max Roof Crush	Curb Wt.
1	71	VW	Beetle	2	2711	1.32	3200	1.63	1807
2	66	Ford	Mustang	2HT	3909	1.75	4620	2.15	2606
3	77	Ford	Mustang	2	4500	3.6	5250	5.05	3000
4	70	Dodge	Dart	2HT	4523	1.0	5500	1.65	3015
5	69	Chevy	Impala	4HT	5000	2.75	6000	4.10	3800
6	69	Chevy	Chevelle	2	4897	2.4	5400	2.83	3265
7	65	Chevy	Impala	4HT	5000	3.6	5280	3.92	3675
8	65	Ford	Galaxie	2HT	5000	2.0	5970	3.00	3541
9	70	Ford	Mustang	2HT	4647	4.3	5120	4.52	3098
10	66	VW	Beetle	2	2579	1.1	3480	1.55	1719
11	64	Dodge	Dart	2HT	4162	0.9	5870	1.59	2775
12	74	Toyota	Corolla	2	2907	1.08	4170	1.73	1938
13	74	Plym	Scamp	2HT	4672	1.66	5250	2.27	3115
14	66	Chevy	Malibu	2HT	4793	1.7	4850	1.72	3195
15	69	Ford	Galaxie	2HT	5000	3.81	5210	4.76	3902
16	74	Chevy	Impala	4HT	5000	9.5	6950	10.60	4427
17	74	Chevy	Laguna	2	5000	3.28	5940	4.26	4061
18	69	Pontiac	Grand Prix	2HT	5000	1.50	5920	5.43	3885
19	72	Chevy	Biscayne	4	5000	3.78	5130	5.08	4171
20	74	Ford	Galaxie	4HT	5000	3.66	5290	4.40	4302

*"HT" denotes true hardtops; all other have B pillars

3.3 Data elements for the statistical analysis

The test procedure for Standard 216 generates 2 crush measurements: the "minimum" roof crush, which is measured precisely at the force level needed to meet the standard and the "maximum" roof crush which occurs at some higher level of force - but the test procedure does not dictate exactly how much higher. A glance at Table 3-1 or Appendix A shows that the maximum crush force reached in the tests has been as little as 3 percent above the standard's minimum requirement (test no. 19) or as much as 39 percent above it (test no. 16). In most cases, though, the test laboratories try for a maximum force approximately 10 percent above the standard's requirement.

For statistical analysis, two measurements are better than one. The "minimum roof crush" is already in a form that can be compared from car to car, since it is measured exactly at the level required by the standard. It will be called CRUSH1. CRUSH2 is an estimate of the amount of crush that occurs at a force 10 percent higher above the standard's requirement. It is estimated by linear interpolation (or extrapolation) of the minimum and maximum roof crush. For example, in test no. 8, the 1965 Ford Galaxie had exactly 2 inches of crush at the "minimum" force of 5000 pounds and exactly 3 inches of crush at 5970 pounds, the maximum force on that test. It is estimated that at 5500 pounds (10 percent above the minimum requirement), CRUSH2 would be $2 + 500/970 = 2.52$ inches. Since most of the tests have a maximum force close to 10 percent above the minimum requirement, CRUSH2 is usually an accurate estimate - and it can be meaningfully compared from car to car. A special case is compliance test 614030 of a 1974 Chevrolet Caprice 4 door hardtop. The test was stopped at 5 inches of crush, before the minimum required force was achieved. The graphs in the test report show 4.5 inches of crush at 4300 pounds and 5 inches at 4400 pounds. By linear extrapolation (the best that can be done under the circumstances), crush is estimated to be 8 inches at 5000 pounds (CRUSH1) and 10.5 inches at 5500 pounds (CRUSH2).

The information in CRUSH1 and CRUSH2 is combined into a single variable, CRUSH3, which is normally distributed and well suited for statistical analyses such as regression. The first step is to rank the 128 test vehicles on CRUSH1 and CRUSH2. For example, the 74 Datsun B210 has the lowest (best) value of CRUSH1, so it receives a rank score of 1 on that attribute; the 76 Datsun 710 is second lowest, so it gets a 2; the used 74 Chevrolet Caprice hardtop is highest, so it gets a 128. The rank scores are nonparametric in the sense that a difference of 1 in rank scores do not correspond to any particular difference in the underlying crush measurement. Next the rank scores R_i are converted into a normally distributed variable Y_i by Blom's formula

$$Y_i = PSI\ ((R_i - .375/128.25)$$

where PSI is the inverse cumulative normal (probit) function [39], p. 362. For example, the 74 Datsun B210 receives a score of -2.59; the 76 Datsun 710 receives a score of -2.24; and the used 74 Caprice, +2.58. The higher the score, the higher the crush. CRUSH3 is the sum of the normalized rank order scores for CRUSH1 and CRUSH2; it is also normally distributed.

3.4 Ranking the cars on crush performance

Table 3-2 ranks the 128 new and used cars on CRUSH1, the amount of roof crush at the force level specified by Standard 216. The new cars have 6 digit HS numbers, while the used cars have 2 digit numbers. Only two tests did not reach the force level within the 5 inches of crush allowed by the standard: both cars were 1974 Chevrolet Caprice/Impala 4 door hardtops, one new and one used. Most cars met the standard easily: 66 percent of them had 2 inches of crush or less and 88 percent had 3 inches or less.

Table 3-3 ranks the cars on CRUSH2, the estimated amount of deformation at a force level 10 percent higher than the Standard 216 requirement. The cars that performed well on CRUSH1 usually also had low CRUSH2, but there are some exceptions. For example, the 1969 Pontiac Grand Prix hardtop ranked 60th in CRUSH1 (1.5 inches) but 110th in CRUSH2 (3.64 inches). There are some cars whose force deflection curve is linear and steep throughout the force levels tested under Standard 216. But there are others whose force deflection curve begins leveling out near the amount required by Standard 216; they sustain a lot more crush if the force is increased another 10 percent. Table 3-3 shows 13 cars with CRUSH2 over 4 inches, including 6 cars over 6 inches. Six of the 13 relatively weak performers are full-sized hardtops and another 2 are full-sized sedans. Four are sporty domestic cars.

Table 3-4 shows the rankings on CRUSH3, the sum of the normalized rank order scores derived from CRUSH1 and CRUSH2. They are the

TABLE 3-2

ROOF CRUSH OF 128 CARS AT FORCE LEVEL REQUIRED BY STANDARD 216
Ranked from Lowest (Best) to Highest (Worst)

OBS	CRUSH1	HS	MY	MMNAME	MODEL	DOORS
1	0.815	614101	74	NISS-B210/1200	B210	2
2	0.825	615857	76	NISS-710	710	2
3	0.900	11	64	DODG-DART	DART	2HT
4	0.900	626784	85	CHEV-SPECTRUM	SPECTRUM	4
5	1.000	4	70	DODG-DART	DART	2HT
6	1.000	624280	83	VW-RABBIT	RABBIT	2
7	1.020	620055	78	VW-RABBIT	RABBIT	4
8	1.025	614335	74	TOYT-COROLLA	COROLLA	2
9	1.038	614902	75	VW-BEETLE	BEETLE	2
10	1.038	615451	76	SAAB-99/99E/900	99GL	4
11	1.060	620056	78	PLYM-HORIZON	HORIZON	4
12	1.063	615447	76	AMER-HORNET/CONC	HORNET	4SW
13	1.070	624568	83	FORD-ESCORT	ESCORT	4
14	1.080	12	74	TOYT-COROLLA	COROLLA	2
15	1.088	614904	75	AMER-PACER	PACER	2
16	1.100	626916	85	DODG-COLT	COLT	4
17	1.100	10	66	VW-BEETLE	BEETLE	2
18	1.100	624279	83	TOYT-TERCEL	TERCEL	4
19	1.130	624592	83	CHEV-CAVALIER	CAVALIER	4
20	1.150	624590	83	CHEV-CHEVETTE	CHEVETTE	2
21	1.150	624275	83	MITS-TREDIA	TREDIA	4
22	1.170	624569	83	NISS-SENTRA	SENTRA	2
23	1.175	615452	76	VOLV-242/244/245	245DL	4SW
24	1.180	627253	85	CHEV-NOVA/TOYT	NOVA	4
25	1.200	626786	85	DODG-LANCER	LANCER	4
26	1.200	624264	84	FORD-TEMPO	TEMPO	4
27	1.200	624277	83	PONT-6000	6000	4
28	1.200	624270	83	HOND-CIVIC	CIVIC	2
29	1.200	620057	78	HOND-ACCORD	ACCORD	2
30	1.200	624278	83	TOYT-CAMRY	CAMRY	4
31	1.210	614901	75	VW-SCIROCCO	SCIROCCO	2
32	1.213	615055	75	PLYM-VAL/DST/SCP	VALIANT	2HT
33	1.250	614100	74	AMER-SPIRIT/GRML	GREMLIN	2
34	1.256	614217	74	DODG-COLT	COLT	4
35	1.263	615569	76	DODG-ASPEN	ASPEN	4SW
36	1.300	626209	84	BUIC-SKYLARK	SKYLARK	4
37	1.300	624740	84	HOND-CIVIC	CIVIC	2
38	1.300	624273	83	MAZD-626	626	4
39	1.300	626205	84	TOYT-COROLLA	COROLLA	4
40	1.300	624274	83	MITS-CORDIA	CORDIA	2
41	1.310	614139	74	PLYM-FURY	FURY	4SW
42	1.320	1	71	VW-BEETLE	BEETLE	2
43	1.325	614214	74	MERC-CAPRI-IMP	CAPRI	2
44	1.330	614144	74	PONT-BONNE/CATAL	SAFARI	4SW
45	1.350	620053	76	PLYM-SAPPORO-IMP	SAPPORO	2
46	1.370	624591	83	PLYM-HORIZON	TURISMO	2
47	1.375	614145	74	DODG-POLARA/MONA	MONACO	4
48	1.375	614143	74	PONT-VENTURA	VENTURA	2
49	1.380	620054	78	TOYT-CRESSIDA	CRESSIDA	4
50	1.400	614903	75	CHRY-CORDOBA	CORDOBA	2
51	1.400	624711	84	PLYM-CHAMP/COLT	COLT	4SW
52	1.400	626208	84	CHEV-CELEBRITY	CELEBRTY	4SW
53	1.400	626206	84	NISS-200	200SX	2
54	1.400	626130	84	PEUG-505/504	505	4SW
55	1.400	626915	85	MITS-GALANT	GALANT	4
56	1.443	615556	76	MAZD-RX4	RX4	2
57	1.445	614338	74	CHRY-NEWPRT/NYEP	NEWPORT	2HT
58	1.475	614390	75	PONT-ASTRE	ASTRE	2SW
59	1.500	624709	84	DODG-DAYTONA	DAYTONA	2
60	1.500	18	69	PONT-GRAND	GRANDPRI	2HT
61	1.500	624742	84	AUDI-5000	5000S	4
62	1.500	624276	83	NISS-PULSAR	PULSAR	4
63	1.500	626207	84	HOND-CIVIC	CIVIC	4SW
64	1.525	615013	75	DODG-COR/CHG/MAG	CORONET	2HT
65	1.600	624269	83	AMER-SPIRIT/GRML	SPIRIT	2
66	1.600	624265	83	FORD-THUNDERBIRD	TBIRD	2
67	1.625	614562	75	CHEV-CAMARO	CAMARO	2
68	1.660	13	74	PLYM-VAL/DST/SCP	SCAMP	2HT
69	1.675	615449	76	BUIC-SKYLARK	SKYLARK	2
70	1.700	14	66	CHEV-MALIBU/CHVL	MALIBU	2HT
71	1.700	624271	83	HOND-PRELUDE	PRELUDE	2
72	1.750	2	66	FORD-MUSTANG	MUSTANG	2HT
73	1.750	626701	85	OLDS-CALAIS	CALAIS	2
74	1.800	627006	85	NISS-810/MAXIMA	MAXIMA	4
75	1.800	624713	84	MAZD-GLC	GLC	2
76	1.825	614337	74	FORD-MUSTANG	MUSTANG	2
77	1.863	614863	75	FORD-PINTO	PINTO	2
78	1.875	714142	74	FORD-MAVERICK	MAVERICK	4
79	1.900	624741	84	ISUZU-I-MARK	IMARK	4
80	.938	614572	75	FORD-GRANADA	GRANADA	2
81	2.000	624263	83	FORD-LTD/GAL/CUS	LTD	4
82	2.000	8	65	FORD-LTD/GAL/CUS	GALAXIE	2HT
83	2.000	624712	84	VW-QUANTUM	QUANTUM	4
84	2.000	626757	85	SUBA-FE/GF/DL/G	GL	2
85	2.000	624763	84	TOYT-COROLLA	COROLLA	2
86	2.025	614671	75	FORD-TORINO/GRAN	TORINO	2HT
87	2.025	615042	75	BUIC-SKYHAWK	SKYHAWK	2
88	2.050	620049	78	MERC-MONARCH	MONARCH	4
89	2.050	620052	78	PONT-PHOENIX	PHOENIX	2
90	2.075	614141	74	CHEV-VEGA	VEGA	2
91	2.100	624262	83	CHEV-CAPRICE/IMP	CAPRICE	4
92	2.125	614870	75	FORD-LTD/GAL/CUS	LTD	4
93	2.125	614140	74	LINC-MARK	MARK4	2HT
94	2.138	615450	76	CHEV-MONZA	MONZA	2
95	2.140	620055	78	CHEV-MONZA	MONZA	2
96	2.250	620050	78	LINC-VERSAILLES	VERSAI	4
97	2.250	614216	74	BUIC-REGAL	CENTURY	2
98	2.250	624798	84	RENA-UNK	SPORTWAG	4SW
99	2.263	615448	76	FORD-TORINO/GRAN	ELITE	2HT
100	2.300	624765	84	RENA-FUEGO	FUEGO	2
101	2.350	620051	78	PONT-LEMANS/TEMP	GRANDAM	2
102	2.395	614336	74	CHEV-MALIBU/CHVL	MALIBU	2
103	2.400	6	69	CHEV-MALIBU/CHVL	CHEVELLE	2
104	2.500	624708	84	PONT-FIERO	FIERO	2
105	2.600	624281	83	VOLV-760	760GLE	4
106	2.613	614591	75	PONT-GRAND	GRANDPRI	2
107	2.700	626765	85	MERC-MERKUR	MERKUR	2
108	2.750	614339	74	BUIC-LESABRE	LESABRE	2HT
109	2.750	5	69	CHEV-CAPRICE/IMP	IMPALA	4HT
110	2.788	615570	76	OLDS-CUTLASS	CUTLASS	2
111	2.800	624267	83	DODG-DODGE	600	4
112	2.800	624272	83	ISUZU-IMPULSE	IMPULSE	2
113	2.825	614202	74	PONT-LEMANS/TEMP	LEMANS	2
114	3.250	624266	83	MERC-CAPRI-COM	CAPRI	2
115	3.260	17	74	CHEV-MALIBU/CHVL	LAGUNA	2
116	3.400	624268	83	RENA-ALLIANCE	ALLIANCE	4
117	3.500	614817	75	CHEV-CAPRICE/IMP	CAPRICE	4HT
118	3.600	624710	84	DODG-CONQUEST	CONQUEST	2
119	3.600	3	77	FORD-MUSTANG	MUSTANG	2
120	3.600	7	65	CHEV-CAPRICE/IMP	IMPALA	4HT
121	3.660	20	74	FORD-LTD/GAL/CUS	GALAXIE	4HT
122	3.780	19	72	CHEV-CAPRICE/IMP	BISCAYNE	4
123	3.810	15	69	FORD-LTD/GAL/CUS	GALAXIE	2HT
124	4.035	614215	74	FORD-LTD/GAL/CUS	GALAXIE	2HT
125	4.300	9	70	FORD-MUSTANG	MUSTANG	2HT
126	4.900	624784	84	FORD-CROWN	CROWNVIC	4
127	8.000	614030	74	CHEV-CAPRICE/IMP	CAPRICE	4HT
128	9.500	16	74	CHEV-CAPRICE/IMP	IMPALA	4HT

TABLE 3-3

ROOF CRUSH OF 128 CARS
AT FORCE LEVEL 10 PERCENT OVER STANDARD 216 SPECIFICATION
Ranked from Lowest (Best) to Highest (Worst)

OBS	CRUSH2	HS	MY	MMNAME	MODEL	DOORS
1	0.95114	615857	76	NISS-710	710	2
2	0.97146	614101	74	NISS-B210/1200	B210	2
3	1.05692	626784	85	CHEV-SPECTRUM	SPECTRUM	4
4	1.06414	11	64	DODG-DART	DART	2HT
5	1.10732	624280	83	VW-RABBIT	RABBIT	2
6	1.12485	614335	74	TOYT-COROLLA	COROLLA	2
7	1.13814	614902	75	VW-BEETLE	BEETLE	2
8	1.14733	620055	78	VW-RABBIT	RABBIT	4
9	1.17564	620056	78	PLYM-HORIZON	HORIZON	4
10	1.18792	615451	76	SAAB-99/99E/900	99GL	4
11	1.20814	626916	85	DODG-COLT	COLT	4
12	1.21263	615447	76	AMER-HORNET/CONC	HORNET	4SW
13	1.22881	10	66	VW-BEETLE	BEETLE	2
14	1.22961	12	74	TOYT-COROLLA	COROLLA	2
15	1.23787	614904	75	AMER-PACER	PACER	2
16	1.26117	624592	83	CHEV-CAVALIER	CAVALIER	4
17	1.26236	624588	83	FORD-ESCORT	ESCORT	4
18	1.29814	624275	83	MITS-TREDIA	TREDIA	4
19	1.30092	4	70	DODG-DART	DART	2HT
20	1.32526	615452	76	VOLV-242/244/245	245DL	4SW
21	1.32692	624589	83	NISS-SENTRA	SENTRA	2
22	1.33974	627253	85	CHEV-NOVA/TOYT	NOVA	4
23	1.34361	624590	83	CHEV-CHEVETTE	CHEVETTE	2
24	1.34700	624279	83	TOYT-TERCEL	TERCEL	4
25	1.35457	620057	78	HOND-ACCORD	ACCORD	2
26	1.35642	624264	84	FORD-TEMPO	TEMPO	4
27	1.36949	624278	83	TOYT-CAMRY	CAMRY	4
28	1.37065	614901	75	VW-SCIROCCO	SCIROCCO	2
29	1.37524	625786	85	DODG-LANCER	LANCER	4
30	1.38590	624270	83	HOND-CIVIC	CIVIC	2
31	1.41321	615055	75	PLYM-VAL/DST/SCP	VALIANT	2HT
32	1.41961	626209	84	BUIC-SKYLARK	SKYLARK	4
33	1.42276	624740	84	HOND-CIVIC	CIVIC	2
34	1.42656	626205	84	TOYT-COROLLA	COROLLA	4
35	1.43221	624277	83	PONT-6000	6000	4
36	1.45000	614144	74	PONT-BONNE/CATAL	SAFARI	4SW
37	1.46700	615569	76	DODG-ASPEN	ASPEN	4SW
38	1.49000	614139	74	PLYM-FURY	FURY	4SW
39	1.49165	1	71	VW-BEETLE	BEETLE	2
40	1.52808	626208	84	CHEV-CELEBRITY	CELEBRTY	4SW
41	1.53725	624273	83	MAZD-626	626	4
42	1.54369	614217	74	DODG-COLT	COLT	4
43	1.55392	624591	83	PLYM-HORIZON	TURISMO	2
44	1.55973	620054	78	TOYT-CRESSIDA	CRESSIDA	4
45	1.57931	624274	83	MITS-CORDIA	CORDIA	2
46	1.58811	626206	84	NISS-200	200SX	2
47	1.59967	626915	85	MITS-GALANT	GALANT	4
48	1.60116	614100	74	AMER-SPIRIT/GRML	GREMLIN	2
49	1.60500	614145	74	DODG-POLARA/MONA	MONACO	4
50	1.62133	626130	84	PEUG-505/504	505	4SW
51	1.62957	626207	84	HOND-CIVIC	CIVIC	4SW
52	1.65442	620053	78	PLYM-SAPPORO-IMP	SAPPORO	2
53	1.67500	614143	74	PONT-VENTURA	VENTURA	2
54	1.70000	614903	75	CHRY-CORDOBA	CORDOBA	2
55	1.70500	614336	74	CHRY-NEWPRT/NYER	NEWPORT	2HT
56	1.72655	624711	84	PLYM-CHAMP/COLT	COLT	4SW
57	1.72975	614214	74	MERC-CAPRI-IMP	CAPRI	2
58	1.73379	615556	76	MAZD-RX4	RX4	2
59	1.76633	624742	84	AUDI-5000	5000S	4
60	1.77500	615013	75	DODG-COR/CHG/MAG	CORONET	2HT
61	1.77553	614890	75	PONT-ASTRE	ASTRE	2SW
62	1.80100	615449	76	BUIC-SKYLARK	SKYLARK	2
63	1.81002	624276	83	NISS-PULSAR	PULSAR	4
64	1.85613	624709	84	DODG-DAYTONA	DAYTONA	2
65	1.80816	14	66	CHEV-MALIBU/CHVL	MALIBU	2HT
66	1.90703	625701	85	OLDS-CALAIS	CALAIS	2
67	1.95575	624271	83	HOND-PRELUDE	PRELUDE	2
68	1.96992	2	66	FORD-MUSTANG	MUSTANG	2HT
69	1.97723	624265	83	FORD-THUNDERBIRD	TBIRD	2
70	2.06715	627006	85	NISS-810/MAXIMA	MAXIMA	4
71	2.15307	13	74	PLYM-VAL/DST/SCP	SCAMP	2HT
72	2.15558	714142	74	FORD-MAVERICK	MAVERICK	4
73	2.16202	626787	85	SUBA-FE/GF/DL/G	GL	2
74	2.23800	614872	75	FORD-GRANADA	GRANADA	2
75	2.23817	624783	84	TOYT-COROLLA	COROLLA	2
76	2.24980	620052	78	PONT-PHOENIX	PHOENIX	2
77	2.25909	620049	78	MERC-MONARCH	MONARCH	4
78	2.26060	620058	78	CHEV-MONZA	MONZA	2
79	2.29875	624741	84	ISUZU-I-MARK	IMARK	4
80	2.32452	615042	75	BUIC-SKYHAWK	SKYHAWK	2
81	2.34876	624262	83	CHEV-CAPRICE/IMP	CAPRICE	4
82	2.36097	624712	84	VW-QUANTUM	QUANTUM	4
83	2.37500	614870	75	FORD-LTD/GAL/CUS	LTD	4
84	2.39785	624798	84	RENA-UNK	SPORTWAG	4SW
85	2.41252	614863	75	FORD-PINTO	PINTO	2
86	2.43000	614216	74	BUIC-REGAL	CENTURY	2
87	2.43700	615448	76	FORD-TORINO/GRAN	ELITE	2HT
88	2.45000	620050	78	LINC-VERSAILLES	VERSAI	4
89	2.45346	624269	83	AMER-SPIRIT/GRML	SPIRIT	2
90	2.46806	615450	76	CHEV-MONZA	MONZA	2
91	2.51546	8	65	FORD-LTD/GAL/CUS	GALAXIE	2HT
92	2.60500	614336	74	CHEV-MALIBU/CHVL	MALIBU	2
93	2.61390	624713	84	MAZD-GLC	GLC	2
94	2.63715	624263	83	FORD-LTD/GAL/CUS	LTD	4
95	2.64727	620051	78	PONT-LEMANS/TEMP	GRANDAM	2
96	2.66224	624706	84	PONT-FIERO	FIERO	2
97	2.67545	614141	74	CHEV-VEGA	VEGA	2
98	2.81300	614891	75	PONT-GRAND	GRANDPRI	2
99	2.81500	614140	74	LINC-MARK	MARK4	2HT
100	2.81863	6	69	CHEV-MALIBU/CHVL	CHEVELLE	2
101	2.88607	624785	84	RENA-FUEGO	FUEGO	2
102	2.96295	624281	83	VOLV-760	760GLE	4
103	2.98500	615570	76	OLDS-CUTLASS	CUTLASS	2
104	3.00000	614339	74	BUIC-LESABRE	LESABRE	2HT
105	3.02500	614202	74	PONT-LEMANS/TEMP	LEMANS	2
106	3.05510	626785	85	MERC-MERKUR	MERKUR	2
107	3.42500	5	69	CHEV-CAPRICE/IMP	IMPALA	4HT
108	3.46250	624267	83	DODG-DODGE	600	4
109	3.49653	624272	83	ISUZU-IMPULSE	IMPULSE	2
110	3.63587	18	69	PONT-GRAND	GRANDPRI	2HT
111	3.70000	614817	75	CHEV-CAPRICE/IMP	CAPRICE	4HT
112	3.75313	624266	83	MERC-CAPRI-COM	CAPRI	2
113	3.7750	614871	75	FORD-TORINO/GRAN	TORINO	2HT
114	3.8013	17	74	CHEV-MALIBU/CHVL	LAGUNA	2
115	3.8892	624710	84	DODG-CONQUEST	CONQUEST	2
116	4.0275	614337	74	FORD-MUSTANG	MUSTANG	2
117	4.1714	7	65	CHEV-CAPRICE/IMP	IMPALA	4HT
118	4.3235	624268	83	RENA-ALLIANCE	ALLIANCE	4
119	4.4700	3	77	FORD-MUSTANG	MUSTANG	2
120	4.5161	9	70	FORD-MUSTANG	MUSTANG	2HT
121	4.9359	20	74	FORD-LTD/GAL/CUS	GALAXIE	4HT
122	4.9950	614862	75	CHEV-CAMARO	CAMARO	2
123	6.0719	15	69	FORD-LTD/GAL/CUS	GALAXIE	2HT
124	6.4150	614215	74	FORD-LTD/GAL/CUS	GALAXIE	2HT
125	6.4823	624784	84	FORD-CROWN	CROWNVIC	4
126	8.7500	19	72	CHEV-CAPRICE/IMP	BISCAYNE	4
127	9.7821	16	74	CHEV-CAPRICE/IMP	IMPALA	4HT
128	10.5000	614030	74	CHEV-CAPRICE/IMP	CAPRICE	4HT

TABLE 3-4

COMBINED NORMALIZED ROOF CRUSH SCORE FOR 128 CARS
Ranked from Lowest (Best) to Highest (Worst)

OBS	CRUSH3	MS	MY	MMNAME	MODEL	DOORS
1	-4.8209	615657	76	NISS-710	710	2
2	-4.8209	614101	74	NISS-B210/1200	B210	2
3	-4.0197	626734	85	CHEV-SPECTRUM	SPECTRUM	4
4	-3.8325	11	64	DODG-DART	DART	2HT
5	-3.5513	624280	83	VW-RABBIT	RABBIT	2
6	-3.2069	614335	74	TOYT-COROLLA	COROLLA	2
7	-3.1884	620055	78	VW-RABBIT	RABBIT	4
8	-3.0969	614902	75	VW-BEETLE	BEETLE	2
9	-2.9071	615451	76	SAAB-99/99E/900	99GL	4
10	-2.8823	620056	78	PLYM-HORIZON	HORIZON	4
11	-2.8101	4	70	DODG-DART	DART	2HT
12	-2.6736	615447	76	AMER-HORNET/CONC	HORNET	4SW
13	-2.5148	626916	85	DODG-COLT	COLT	4
14	-2.4936	12	74	TOYT-COROLLA	COROLLA	2
15	-2.4191	10	66	VW-BEETLE	BEETLE	2
16	-2.4186	624588	83	FORD-ESCORT	ESCORT	4
17	-2.4107	614904	75	AMER-PACER	PACER	2
18	-2.2230	624592	83	CHEV-CAVALIER	CAVALIER	4
19	-2.0993	624275	83	MITS-TREDIA	TREDIA	4
20	-2.0281	624279	83	TOYT-TERCEL	TERCEL	4
21	-1.9527	615452	76	VOLV-242/244/245	245DL	4SW
22	-1.9507	624589	83	NISS-SENTRA	SENTRA	2
23	-1.9364	624590	83	CHEV-CHEVETTE	CHEVETTE	2
24	-1.8591	627253	85	CHEV-NOVA/TOYT	NOVA	4
25	-1.6726	620057	78	HOND-ACCORD	ACCORD	2
26	-1.6444	624264	84	FORD-TEMPO	TEMPO	4
27	-1.6168	624278	83	TOYT-CAMRY	CAMRY	4
28	-1.5635	626786	85	DODG-LANCER	LANCER	4
29	-1.5377	624270	83	HOND-CIVIC	CIVIC	2
30	-1.4960	614901	75	VW-SCIROCCO	SCIROCCO	2
31	-1.4149	624277	83	PONT-6000	6000	4
32	-1.3955	615055	75	PLYM-VAL/DST/SCP	VALIANT	2HT
33	-1.2291	626209	84	BUIC-SKYLARK	SKYLARK	4
34	-1.2046	624740	84	HOND-CIVIC	CIVIC	2
35	-1.1805	626205	84	TOYT-COROLLA	COROLLA	4
36	-1.1792	615569	76	DODG-ASPEN	ASPEN	4SW
37	-1.0916	614217	74	DODG-COLT	COLT	4
38	-1.0206	624273	83	MAZD-626	626	4
39	-1.0203	614139	74	PLYM-FURY	FURY	4SW
40	-1.0015	614144	74	PONT-BONNE/CATAL	SAFARI	4SW
41	-0.9890	614100	74	AMER-SPIRIT/GRML	GREMLIN	2
42	-0.9760	1	71	VW-BEETLE	BEETLE	2
43	-0.9347	624274	83	MITS-CORDIA	CORDIA	2
44	-0.8033	624591	83	PLYM-HORIZON	TURISMO	2
45	-0.7357	626208	84	CHEV-CELEBRITY	CELEBRTY	4SW
46	-0.7198	620054	78	TOYT-CRESSIDA	CRESSIDA	4
47	-0.6464	614145	74	DODG-POLARA/MONA	MONACO	4
48	-0.6376	620053	78	PLYM-SAPPORO-IMP	SAPPORO	2
49	-0.6067	626206	84	NISS-200	200SX	2
50	-0.5859	626915	85	MITS-GALANT	GALANT	4
51	-0.5605	614214	74	MERC-CAPRI-IMP	CAPRI	2
52	-0.5653	614143	74	PONT-VENTURA	VENTURA	2
53	-0.5242	626130	84	PEUG-505/504	505	4SW
54	-0.4436	614903	75	CHRY-CORDOBA	CORDOBA	2
55	-0.4033	624711	84	PLYM-CHAMP/COLT	COLT	4SW
56	-0.3355	626207	84	HOND-CIVIC	CIVIC	4SW
57	-0.33387	614332	74	CHRY-NEWPRT/NYER	NEWPORT	2HT
58	-0.29429	615856	76	MAZD-RX4	RX4	2
59	-0.19585	614890	75	PONT-ASTRE	ASTRE	2SW
60	-0.17619	624742	84	AUDI-5000	5000S	4
61	-0.09784	615013	75	DODG-COR/CHG/MAG	CORONET	2HT
62	-0.09751	624276	83	NISS-PULSAR	PULSAR	4
63	-0.07626	624709	84	DODG-DAYTONA	DAYTONA	2
64	0.03918	615449	76	BUIC-SKYLARK	SKYLARK	2
65	0.10761	624265	83	FORD-THUNDERBIRD	TBIRD	2
66	0.12732	14	66	CHEV-MALIBU/CHVL	MALIBU	2HT
67	0.15643	624271	83	HOND-PRELUDE	PRELUDE	2
68	0.15633	626701	85	OLDS-CALAIS	CALAIS	2
69	0.19585	13	74	PLYM-VAL/DST/SCP	SCAMP	2HT
70	0.22547	2	66	FORD-MUSTANG	MUSTANG	2HT
71	0.30442	627006	85	NISS-310/MAXIMA	MAXIMA	4
72	0.41411	714142	74	FORD-MAVERICK	MAVERICK	4
73	0.49449	614872	75	FORD-GRANADA	GRANADA	2
74	0.51833	624269	83	AMER-SPIRIT/GRML	SPIRIT	2
75	0.53691	626787	85	SUBA-FE/GF/DL/G	GL	2
76	0.57461	624741	84	ISUZU-I-MARK	IMARK	4
77	0.57669	624753	84	TOYT-COROLLA	COROLLA	2
78	0.65883	614863	75	FORD-PINTO	PINTO	2
79	0.71447	620052	78	PONT-PHOENIX	PHOENIX	2
80	0.71899	624712	84	VW-QUANTUM	QUANTUM	4
81	0.73457	620049	78	MERC-MONARCH	MONARCH	4
82	0.75193	615042	75	BUIC-SKYHAWK	SKYHAWK	2
83	0.79618	624713	84	MAZD-GLC	GLC	2
84	0.87185	624262	83	CHEV-CAPRICE/IMP	CAPRICE	4
85	0.90362	620058	76	CHEV-MONZA	MONZA	2
86	0.91356	8	65	FORD-LTD/GAL/CUS	GALAXIE	2HT
87	0.94775	614870	75	FORD-LTD/GAL/CUS	LTD	4
88	0.95288	624263	83	FORD-LTD/GAL/CUS	LTD	4
89	0.98865	18	69	PONT-GRAND	GRANDPRI	2HT
90	1.07626	624798	84	RENA-UNK	SPORTWAG	4SW
91	1.11831	614216	74	BUIC-REGAL	CENTURY	2
92	1.13391	615450	76	CHEV-MONZA	MONZA	2
93	1.16217	620050	78	LINC-VERSAILLES	VERSAI	4
94	1.19056	615448	76	FORD-TORINO/GRAN	ELITE	2HT
95	1.20630	614141	74	CHEV-VEGA	VEGA	2
96	1.31348	614140	74	LINC-MARK	MARK4	2HT
97	1.38113	614336	74	CHEV-MALIBU/CHVL	MALIBU	2
98	1.42445	620051	78	PONT-LEMANS/TEMP	GRANDAM	2
99	1.51718	614337	74	FORD-MUSTANG	MUSTANG	2
100	1.53127	624708	84	PONT-FIERO	FIERO	2
101	1.54927	624785	84	RENA-FUEGO	FUEGO	2
102	1.60376	6	69	CHEV-MALIBU/CHVL	CHEVELLE	2
103	1.61007	614871	75	FORD-TORINO/GRAN	TORINO	2HT
104	1.63932	614891	75	PONT-GRAND	GRANDPRI	2
105	1.67786	614862	75	CHEV-CAMARO	CAMARO	2
106	1.71420	624281	83	VOLV-760	760GLE	4
107	1.87755	614339	74	BUIC-LESABRE	LESABRE	2HT
108	1.88877	626785	85	MERC-MERKUR	MERKUR	2
109	1.89946	615570	76	OLDS-CUTLASS	CUTLASS	2
110	1.96698	5	69	CHEV-CAPRICE/IMP	IMPALA	4HT
111	2.06531	614202	74	PONT-LEMANS/TEMP	LEMANS	2
112	2.10115	624267	83	DODG-DODGE	600	4
113	2.13361	624272	83	ISUZU-IMPULSE	IMPULSE	2
114	2.33349	624266	83	MERC-CAPRI-DOM	CAPRI	2
115	2.42876	614817	75	CHEV-CAPRICE/IMP	CAPRICE	4HT
116	2.45213	17	74	CHEV-MALIBU/CHVL	LAGUNA	2
117	2.67667	624268	83	RENA-ALLIANCE	ALLIANCE	4
118	2.68743	624710	84	DODG-CONQUEST	CONQUEST	2
119	2.77745	7	65	CHEV-CAPRICE/IMP	IMPALA	4HT
120	2.87984	3	77	FORD-MUSTANG	MUSTANG	2
121	3.11874	20	74	FORD-LTD/GAL/CUS	GALAXIE	4HT
122	3.40350	9	70	FORD-MUSTANG	MUSTANG	2HT
123	3.41511	15	69	FORD-LTD/GAL/CUS	GALAXIE	2HT
124	3.59666	614215	74	FORD-LTD/GAL/CUS	GALAXIE	2HT
125	3.67318	19	72	CHEV-CAPRICE/IMP	BISCAYNE	4
126	3.95111	624734	84	FORD-CROWN	CROWNVIC	4
127	4.82085	16	74	CHEV-CAPRICE/IMP	IMPALA	4HT
128	4.82085	614030	74	CHEV-CAPRICE/IMP	CAPRICE	4

basic data for the subsequent analyses of this Chapter. It is obvious that most of the good performers are small cars while many of the weaker performers are large cars. It is also noticeable that Volkswagen, Chrysler Corporation and AMC cars tend to have stronger than average roofs.

3.5 Comparison of new and used cars

Before the combined data set of new and used cars is extensively analyzed, it is proper to investigate if vehicle age is itself a factor in test performance - e.g., if roof crush strength deteriorates significantly as a car ages. If vehicle age makes a big difference, it would be inappropriate to compare directly the performance of post-standard cars (new when tested) to pre-standard cars (old when tested).

The final test matrix for the used cars includes 6 vehicles whose make, model, model year and body type more or less matches cars that were compliance tested when new. The values of CRUSH3 for the used and new cars in the 6 matched pairs are as follows:

Used Car		New Car		
MY/Make/Model	CRUSH3	MY/Make/Model	CRUSH3	Difference
74 Toyota Corolla	-2.49	74 Toyota Corolla	-3.27	.78
74 Plymouth Scamp	.20	75 Plymouth Scamp	-1.39	1.59
74 Chevy Laguna	2.45	74 Chevy Malibu	1.38	1.07
77 Ford Mustang	2.88	74 Ford Mustang	1.52	1.36
74 Ford Galaxie	3.12	74 Ford Galaxie	3.60	- .48
74 Chevy Impala	4.82	74 Chevy Caprice	4.82	none
AVERAGE	1.83		1.11	.72

The used Ford Galaxie hardtop actually performed better than the new one and the used and new full-sized Chevrolet hardtops had equal results, but the other 4 cars did better new than used. The difference of the CRUSH3 values can be treated as a normal variate and t tested. The average difference is .72 in favor of the new car and the sample standard deviation is .806. With 6 observations, that gives a t value of 2.19 with 5 degrees of freedom, which is not statistically significant at alpha = .05, although it is significant at alpha = .10 (equivalent to a one-tailed test with alpha = .05). In other words, it cannot be definitely concluded that used cars have lower roof crush resistance, but the data lean in that direction.

If the observed difference between new and used cars is real, what does it amount to in practical terms? The average value of CRUSH3 is 1.83 for the 6 used cars and 1.11 for the 6 new cars. In Table 3-4, a CRUSH3 of 1.83 corresponds to 107th place among the 128 cars; a CRUSH3 of 1.11 corresponds to 91st place. In Table 3-2, the 107th car had a "minimum" roof crush of 2.7 inches and the 91st car, 2.1 inches - i.e., a difference of about 0.6 inches on the compliance test for Standard 216. In practical terms, that is a negligible deterioration for a 14 year old car relative to a new car.

In the remaining analyses of the chapter, vehicle age will not be considered as a separate factor and the results for old and new cars will be considered equivalent. Although that may cause a slight bias against the pre-standard cars, it simplifies the analysis.

3.6 <u>A simple model: no adjustment for market class or manufacturer</u>

The analysis now returns to the full data set of 128 test vehicles of model years 1964-85. Figure 3-1 is a scattergram of the individual test results by CRUSH3 (overall roof crush resistance) and model year. The data points are usually represented by the A's on the graph; however, when two cars try to occupy the same spot on the graph, they are shown by "B," three by "C," etc. It is obvious from Figure 3-1 that the variation among cars within a model year is far greater than the variation between model years. It is hard to see any long-term trend in Figure 3-1.

Figure 3-2 shows the average value of CRUSH3 by model year. Moreover, model years with just one or two observations have been grouped with nearby years: the points with MY 64-66 are all grouped as "66"; 69-72 as "70"; and 76-77 as "76." Figure 3-2 suggests that cars of the mid 1960's had quite strong roofs, with an average CRUSH3 of -0.4. By 1970, roof strength had deteriorated to +1.4. Roof strength improved steadily in cars of the early 1970's and returned to -0.5 in 1976-78, with similar values thereafter.

One problem with Figure 3-2 is that the results are affected by the particular sample of makes and models that NHTSA chose for compliance testing in a given model year. Specifically, in recent years, NHTSA has emphasized small, mostly foreign cars which tend to have better than average roof crush resistance (see Section 3.1). It is appropriate to examine some of the factors that are correlated with roof strength and to

FIGURE 3-1: Scattergram of CRUSH3 (Unadjusted Crush Score) by Model Year

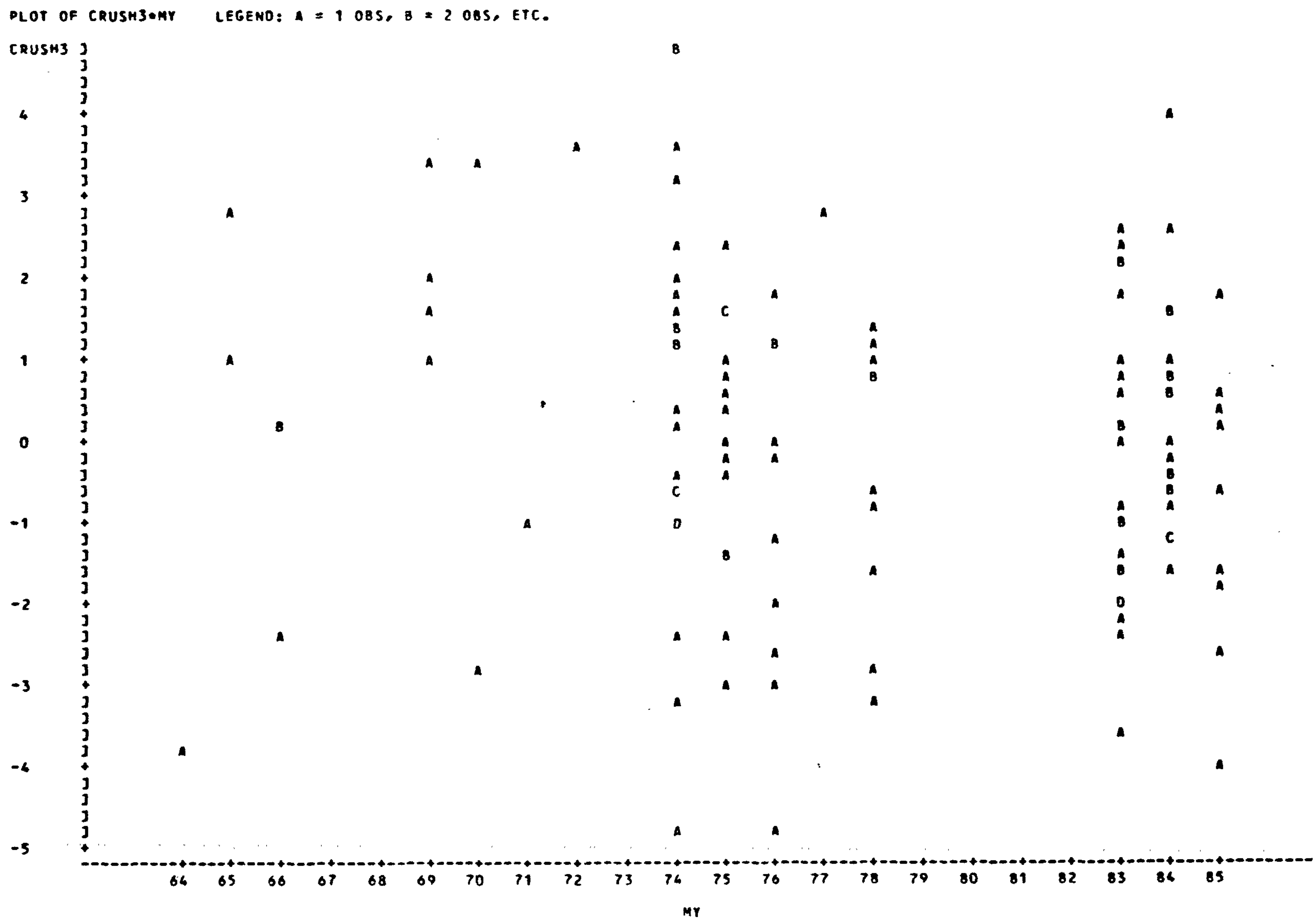
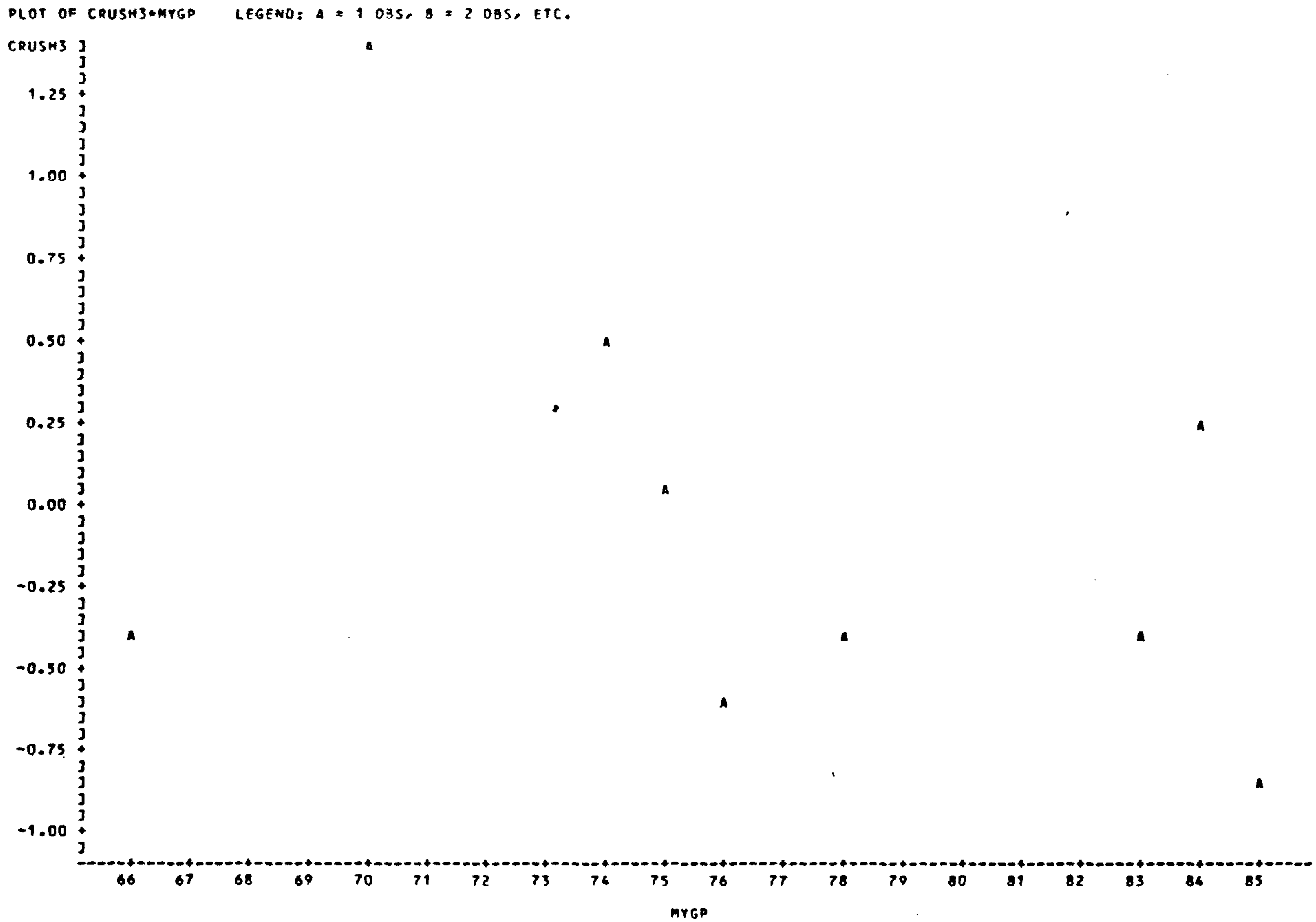


FIGURE 3-2: Average Value of CRUSH3 (Unadjusted Crush Score) by Model Year (Grouped)



adjust for those which are confounded with NHTSA's car selection process for compliance tests.

In Sections 3.4 and 3.5, examination of the individual test results suggested possible differences among companies. Indeed, the average values of CRUSH3 do vary by manufacturer:

+0.83	General Motors	-1.39	American Motors
+1.29	Ford	-1.04	Japan
-0.84	Chrysler	-0.84	Europe

Chrysler has substantially lower roof crush than Ford or GM even though the cars are more or less the same size. The low levels of roof crush for imported cars could be due to their smaller size.

A good way to study the effect of car size or body style is to use the 7 market classes defined in detail in Section 5.4. These classes are

1. Volkswagens
2. All imports other than Volkswagens
3. Domestic subcompacts
4. Domestic compacts
5. Domestic intermediates
6. Large domestic cars
7. Sporty domestic cars

(The 1983 Ford Thunderbird and 1984 Pontiac Fiero are not assigned to any of these groups in Chapters 5-7. Here, so as to avoid missing data, they are assigned to groups 5 and 7, respectively.) The presence or absence of a B pillar is another potentially important factor in roof crush strength. The average values of CRUSH3 by market class and body type are:

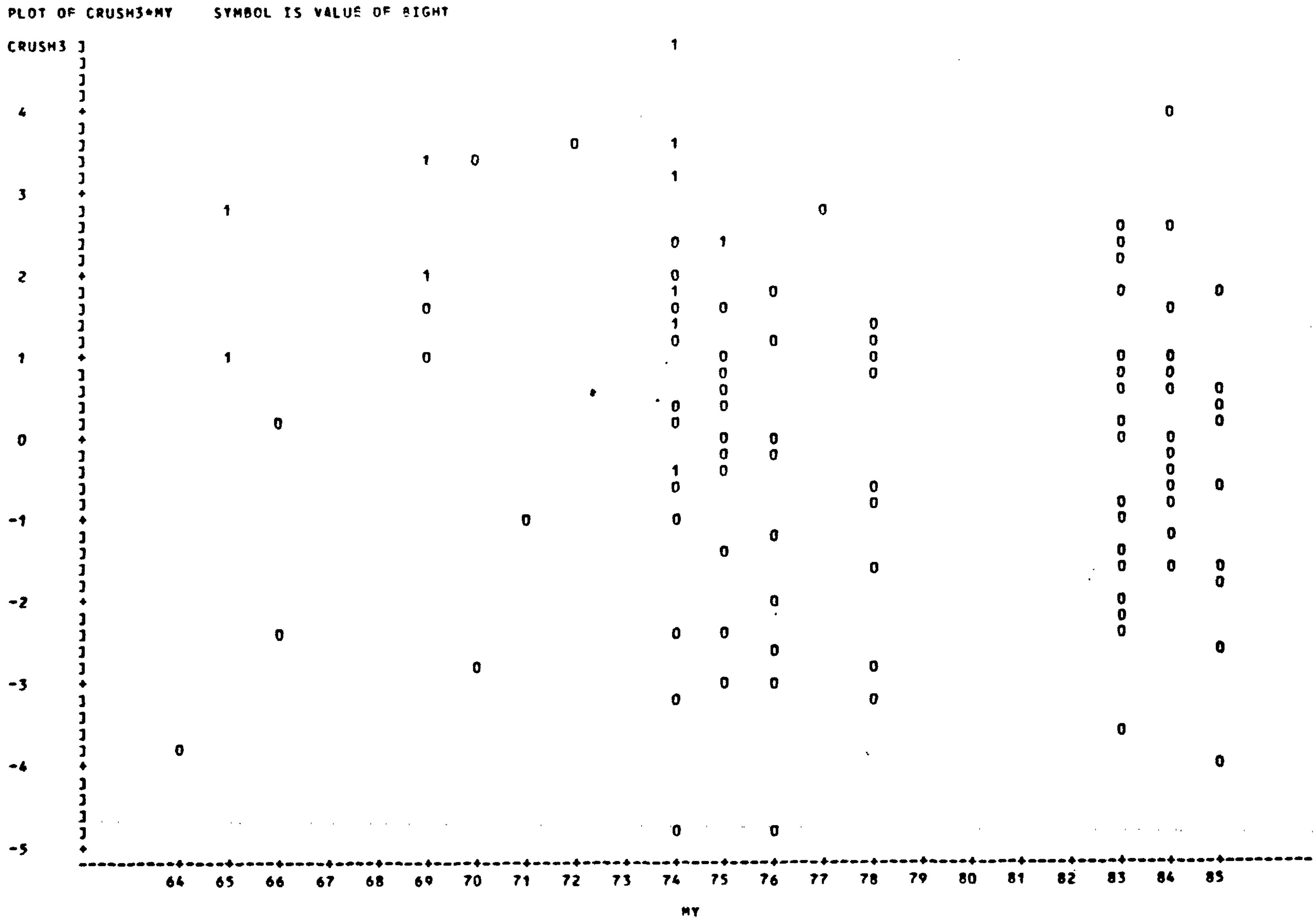
	Sedans	True Hardtops
1. Volkswagens	-2.00	n.a.
2. All other imports	-0.75	n.a.
3. Domestic subcompacts	-0.48	n.a.
4. Domestic compacts	-0.60	-1.97
5. Domestic intermediates	+0.90	+0.76
6. Large domestic cars	+0.97	+2.55
7. Sporty domestic cars	+1.99	+1.81

Intermediate, full-sized and sporty cars are worse than average, while Volkswagens are strong even relative to other small cars. What is especially interesting in the preceding table is that the effect of B pillars is not uniform. Full-sized hardtops are substantially worse than full-sized sedans; in fact they are the worst of all groups. But among intermediates and sporty cars, there is little difference between true hardtops and pillared cars. Among compacts, hardtops even seem to do better, but this may be because the hardtops are all Chrysler corporation cars and the sedans are not.

Figure 3-3 is a scattergram of the data points by CRUSH3 and model year, with full-sized hardtops indicated by "1" and <u>all</u> other cars, by "0." (If 2 or more data points occupy the same spot, only the lowest number is shown on the graph.) Up to model year 1975, big hardtops account for a large percentage of the worst performers. After 1975, few were produced.

Figure 3-4 displays the average value of CRUSH3 by market class and model year (grouped as in Figure 3-2). The numbers on the graph indicate the market class. The 5's, 6's and 7's are consistently at the top, showing that larger cars have always experienced more crush at the force levels specified in the Standard 216 compliance test.

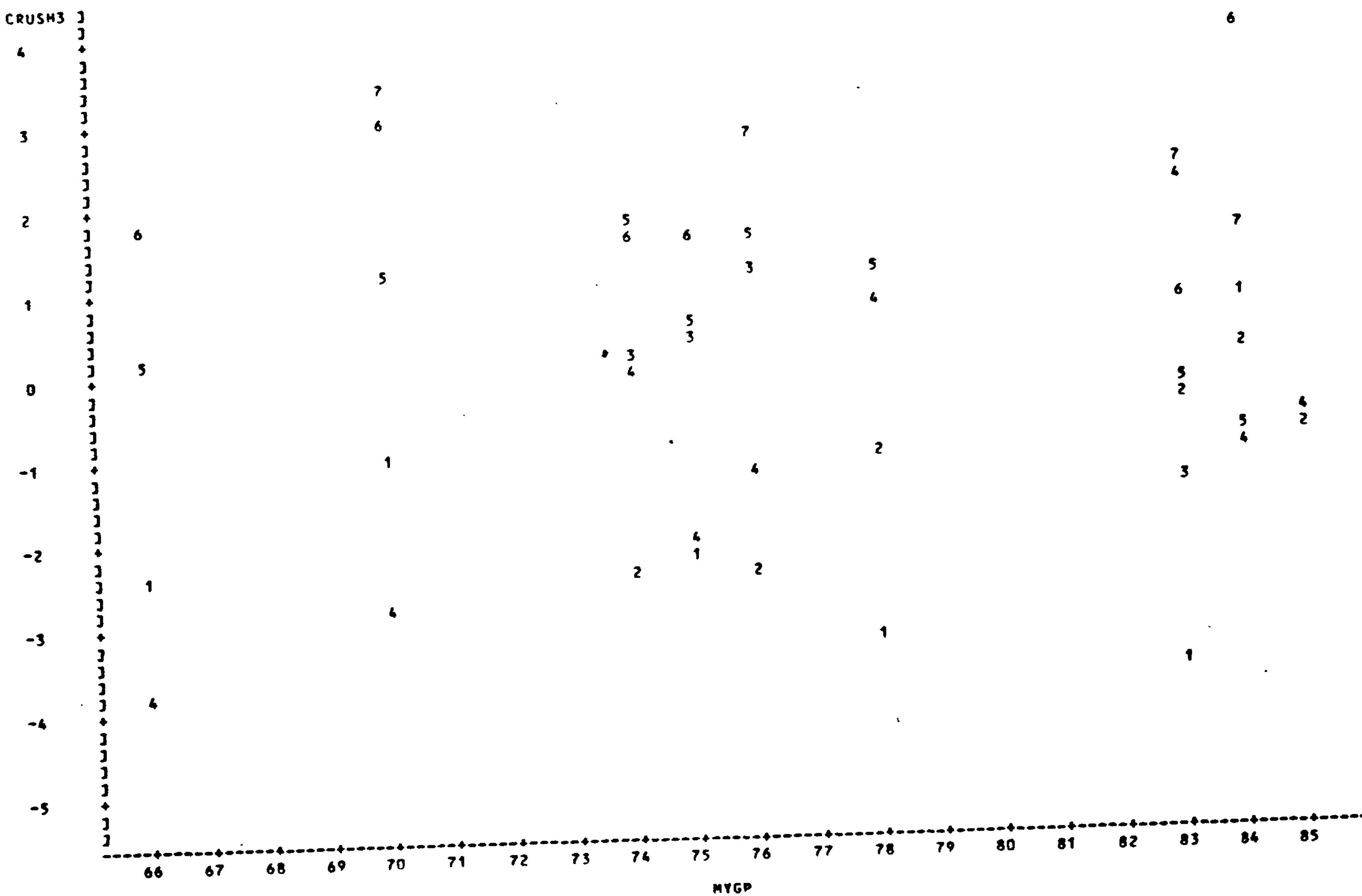
FIGURE 3-3: Scattergram of CRUSH3 (Unadjusted Crush Score) by Model Year and Body Style
(1 = full-sized hardtop; 0 = any other car)



NOTE: 28 OBS HIDDEN

FIGURE 3-4: Average Value of CRUSH3 (Unadjusted Crush Score) by Model Year (Grouped) and Market Class

PLOT OF CRUSH3*MYGP   SYMBOL IS VALUE OF CARGP



NOTE: 4 OBS HIDDEN

3.7 A model which adjusts for market class and manufacturer

Manufacturer, market class and body style are correlated with performance on the Standard 216 test (body style, primarily for large cars). They are also correlated with one another - e.g., imported cars are mostly small. Manufacturer and market class are confounded with model year in the sense that NHTSA may have emphasized certain groups of cars for compliance testing in certain years. Body style (hardtop vs. sedan) is also associated with model year, but for a different reason: few hardtops were produced after 1976. What is needed is a model that properly identifies the effect of each factor. It should then filter out the effects of manufacturer and market class, since they are nuisance factors confounded with the sample selection. But it should not filter out the effect of body style, since the elimination of true hardtops may have been the key measure that improved roof crush strength.

The first step is a linear regression of CRUSH3 by manufacturer, market class and a variable called "big hardtop." Manufacturer is a categorical variable with categories, GM, Ford, Chrysler, AMC, Japan and Europe. Market class is a categorical variable with categories 1-7 as defined above. "Big hardtop" is set equal to 1 for true hardtops of market class 6, zero otherwise. Each of the 128 tests is a data point. The regression coefficients are:

Intercept	+2.26		
GM	-0.38	AMC	-1.51
Ford	-0.29	Japan	-1.23
Chrysler	-1.36		
1. Volkswagen	-4.26	4. Compact	-2.22
2. Other import	-2.07	5. Intermediate	-0.94
3. US Subcompact	-2.04	6. Full sized	-0.65
Big hardtop	+1.38		

The coefficients for Europe and market class 7 (sporty cars) are implicitly zero. R squared is .45, an adequate correlation. Essentially the model says that small cars have stronger roofs than large cars. Big hardtops are the worst and sporty cars are second worst. Chrysler and AMC do better on the Standard 216 test than GM and Ford cars of the same size. Japanese cars and Volkswagens do better than other European cars.

The next step is to use the regression coefficients to adjust CRUSH3 by manufacturer and market class. Define

$$\text{CRUSH4} = \text{CRUSH3} - 2.26 + \begin{cases} .38 \text{ if mfr.=GM} \\ .29 \text{ if mfr.=Ford} \\ 1.36 \text{ if mfr.=Chrys} \\ 1.51 \text{ if mfr.=AMC} \\ 1.23 \text{ if mfr.=Japan} \end{cases} + \begin{cases} 4.26 \text{ if mkt class=1} \\ 2.07 \text{ if mkt class=2} \\ 2.05 \text{ if mkt class=3} \\ 2.22 \text{ if mkt class=4} \\ .94 \text{ if mkt class=5} \\ .65 \text{ if mkt class=6} \end{cases}$$

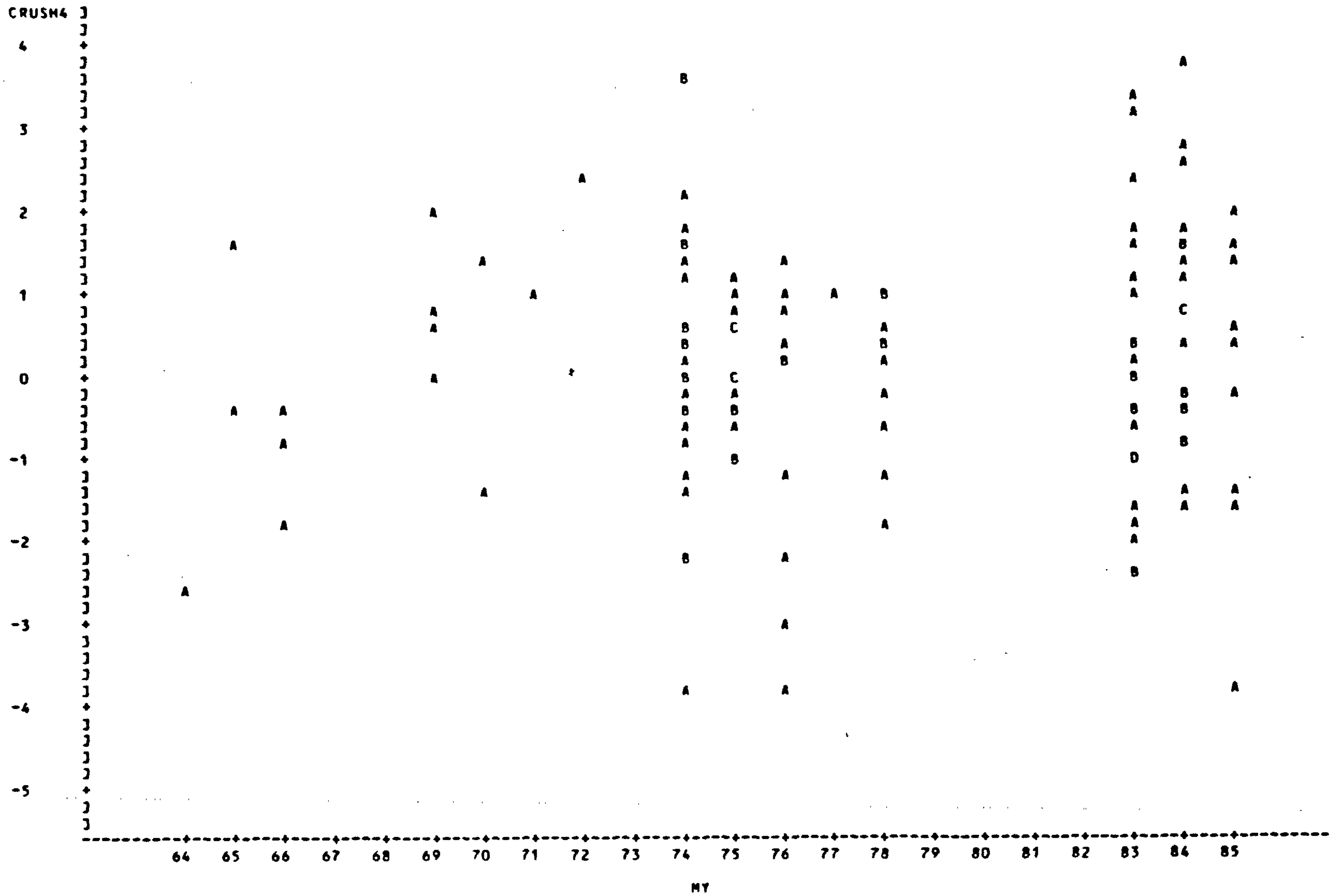
Note that CRUSH4 filters out the effects identified by the regression for manufacturer and market class, which are nuisance factors confounded with the sample selection. But it does <u>not</u> filter out the effect of "big hardtop," since the elimination of true hardtops may have been the key measure that improved roof crush strength.

Figure 3-5 is a scattergram of CRUSH4 (adjusted roof crush resistance) by model year. The data points are usually represented by the A's on the graph; however, when two cars try to occupy the same spot on the graph, they are shown by "B," three by "C," etc. A comparison of Figure 3-5 with Figure 3-1 (unadjusted crush resistance) shows that the adjustment procedure improved the values for earlier model years (where

FIGURE 3-5: Scattergram of CRUSH4 (Adjusted Crush Score) by Model Year

ROOF CRUSH TEST DATA ADJUSTED FOR CARGP AND MANUFACTURER

PLOT OF CRUSH4*MY   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



mostly large cars were tested) and worsened the results for more recent years (where smaller cars were tested). It also reduced some of the variation within model years, although this variation is still larger than any trend across model years. The only long-term trend visible in Figure 3-5 is that cars of the mid 1960's had consistently stronger roofs than average.

Figure 3-6 is a scattergram of CRUSH4 by model year, with full-sized hardtops indicated by "1" and <u>all</u> other cars, by "0." Even after the adjustment procedure (which benefits big cars and GM and Ford products), big hardtops still account for a large percentage of the worst performers in model years 1965-75. The virtual termination of hardtop production after 1976 helped get rid of these poor performers.

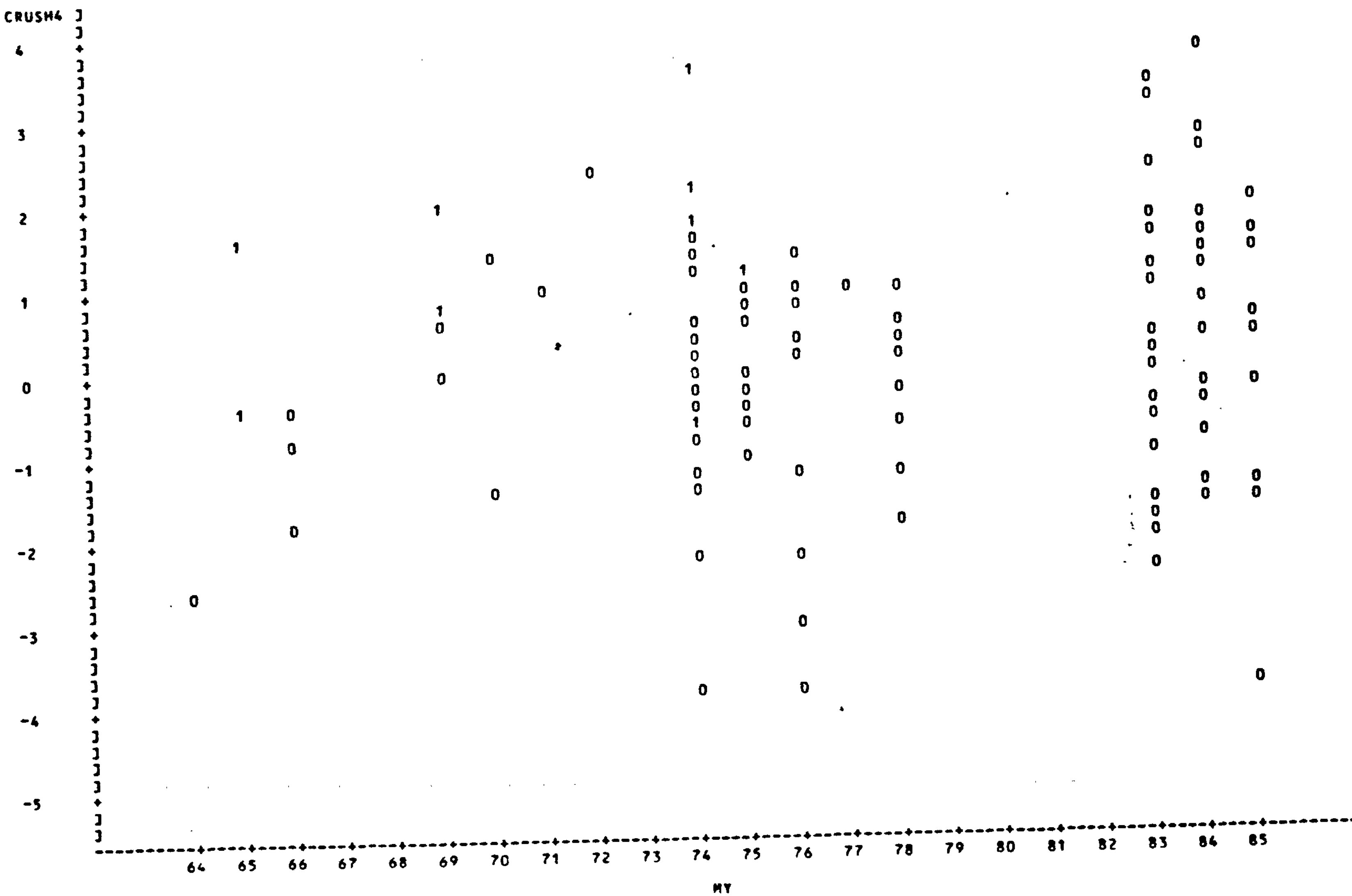
Figure 3-7 displays the average value of CRUSH4 by market class and model year. Moreover, model years with just one or two observations have been grouped with nearby years as in Figure 3-4 (same graph for unadjusted data). The numbers on the graph indicate the market class. A comparison with Figure 3-4 indicates that the adjustment procedure does a good job of scrambling the rank order of the market classes - i.e., filtering out the effect of market class. The exception is that large cars (class 6) are still at or near the top before model year 1976, but this is due to the poor performance of large hardtops, not the effect of market class.

Finally, Figure 3-8 shows the average value of CRUSH4, the

FIGURE 3-6: Scattergram of CRUSH4 (Adjusted Crush Score) by Model Year and Body Style (1 = full-sized hardtop; 0 = any other car)

ROOF CRUSH TEST DATA ADJUSTED FOR CARGP AND MANUFACTURER

PLOT OF CRUSH4*MY SYMBOL IS VALUE OF BIGHT

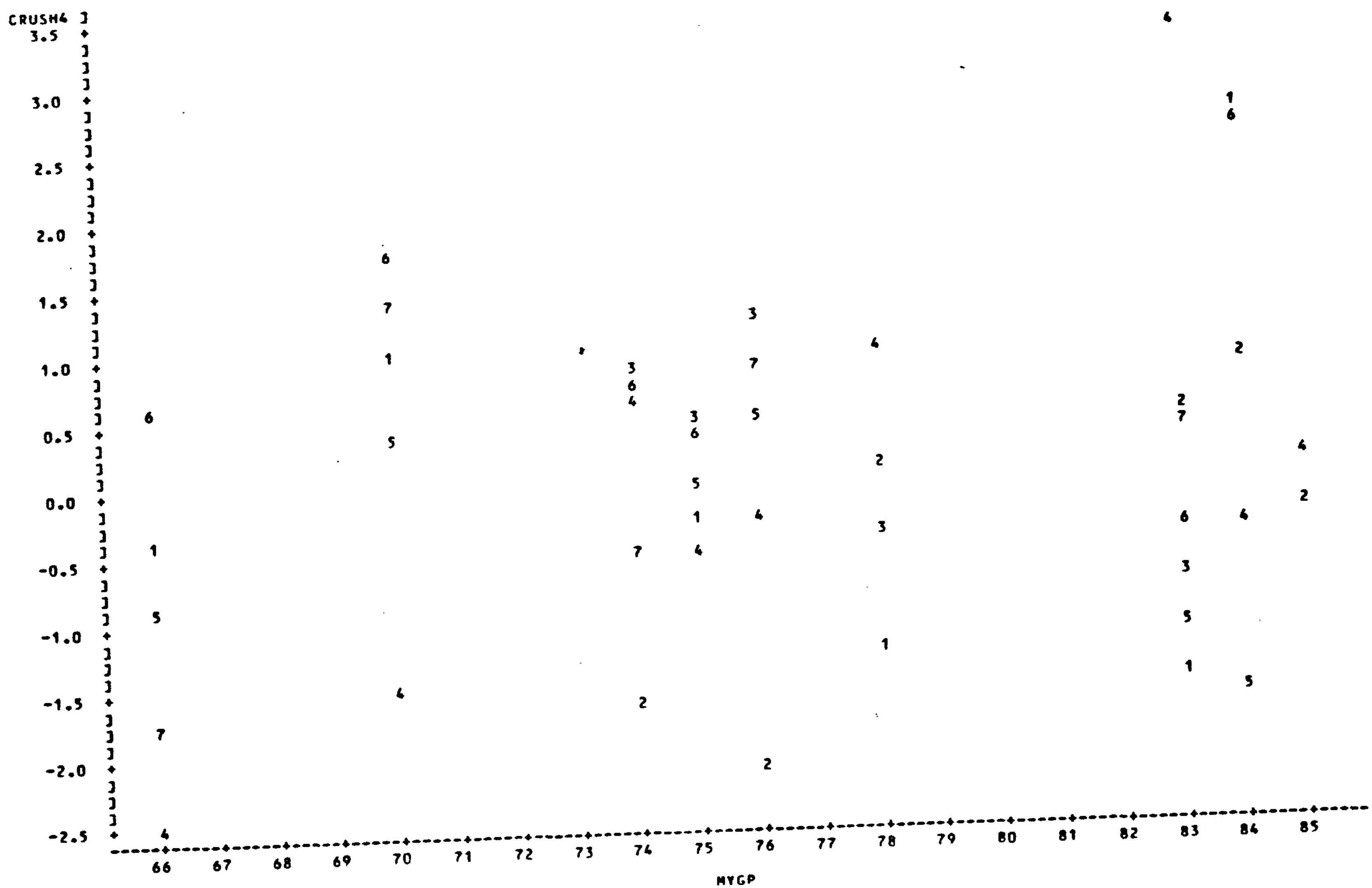


NOTE: 29 OBS HIDDEN

FIGURE 3-7: Average Value of CRUSH4 (Adjusted Crush Score) by Model Year (Grouped) and Market Class

ROOF CRUSH TEST DATA ADJUSTED FOR CARGP AND MANUFACTURER

PLOT OF CRUSH4*MYGP   SYMBOL IS VALUE OF CARGP

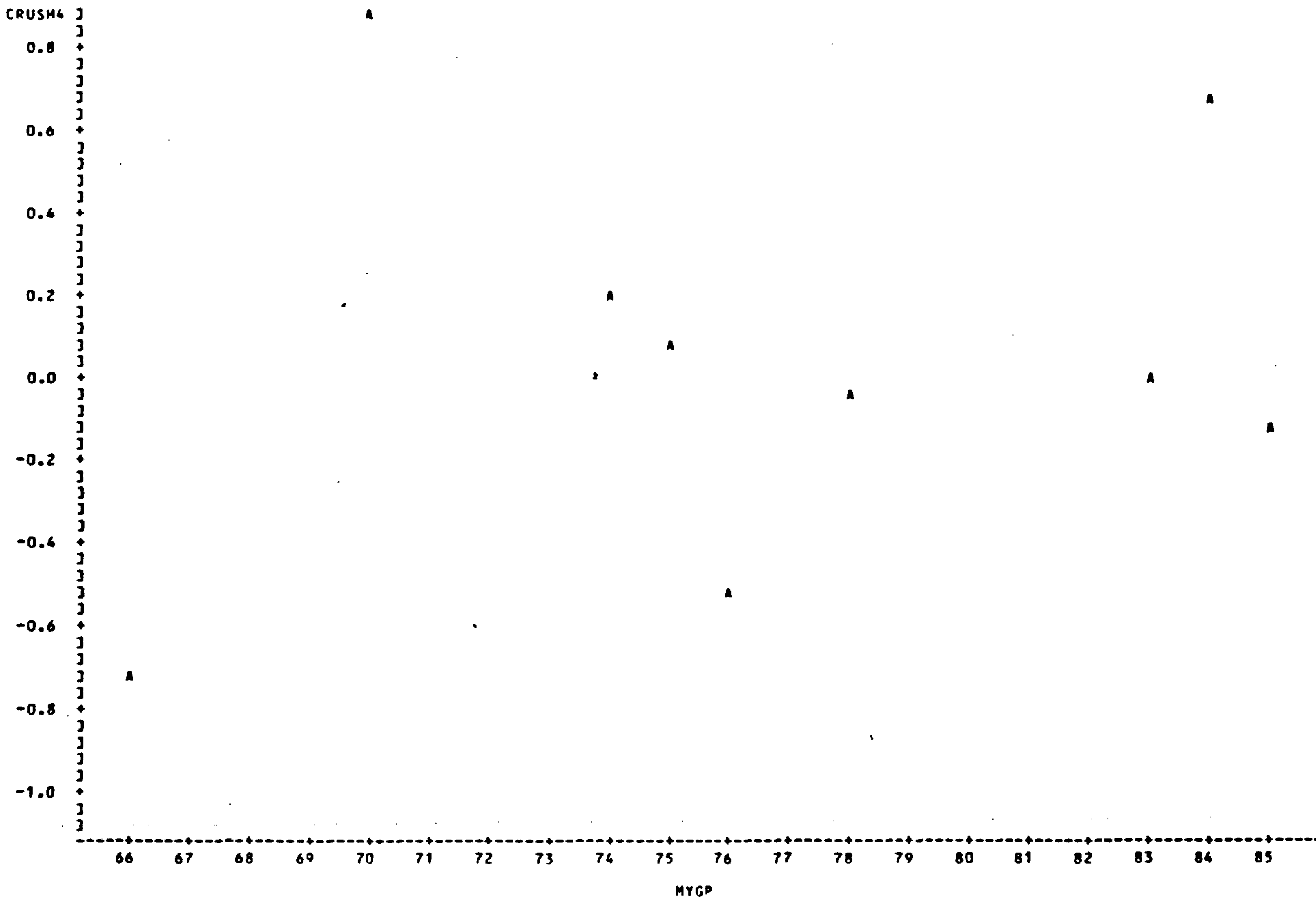


NOTE: 4 OBS HIDDEN

FIGURE 3-8: Average Value of CRUSH4 (Adjusted Crush Score) by Model Year (Grouped)

ROOF CRUSH TEST DATA ADJUSTED FOR CARGP AND MANUFACTURER

PLOT OF CRUSH4*MYGP   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



adjusted roof crush, by model year. Figure 3-8 suggests that cars of the mid 1960's may have had the strongest roofs, with an average CRUSH4 of -0.7 - all the more remarkable because many of these cars were hardtops and all were at least 22 years old at the time they were tested. By 1970, adjusted roof strength had deteriorated to +0.9, its worst level. CRUSH4 improved steadily in cars of the early 1970's was close to 0 (i.e., the average value for all the tests) in model years 1974-75, as hardtops were converted to pillared vehicles and Standard 216 took effect. It has remained close to 0 ever since.

The tests reviewed in this chapter might not support definitive conclusions because they were limited to a relatively small sample of cars and because the Standard 216 test is only one way to measure roof strength. Nevertheless, they do support some ideas about roof strength: hardtops, per se, need not have weak roofs - as evidenced by the test results for cars of the mid 1960's, smaller hardtops, and Chrysler products. Cars of the mid 1960's probably would have had little trouble meeting Standard 216: the ones tested here may have been among the weakest and they met the standard easily. The safety problem, if there ever was one, may have begun in the later 1960's, when it was stylish for large cars to have a wide, flat roof, a highly raked windshield; thin A pillars and no B pillars. All of those styling touches could reduce resistance to vertical loads. The combination of Standard 216, other safety considerations and changes in styling helped eliminate the hardtop designs with the poorest performance.

CHAPTER 4

ROOF CRUSH STRENGTH BY MODEL YEAR, BASED ON ROLLOVER CRASHES

The National Accident Sampling System (NASS), National Crash Severity Study (NCSS) and Multidisciplinary Accident Investigation (MDAI) files contain detailed investigations of 2000 rollover crashes of passenger cars. The files use a Collision Deformation Classification (CDC), which includes a numerical Deformation Extent Guide for roof crush. The average value of the deformation extent, by model year shows the trend in roof crush resistance in actual crashes - after the values are adjusted for car size and sampling or measurement differences between the data files.

The analysis shows that roof crush resistance significantly improved in the mid 1970's, as Standard 216 took effect and manufacturers stopped producing hardtops. Average deformation extent, as measured by the CDC, dropped from 3.7 to 3.54. Although statistically significant, the reduction is small in practical terms. Roof deformation extent zones are about 5 inches wide; an average reduction of 0.16 zones corresponds to approximately 0.8 inches reduction in average crush.

The analysis confirms the test results of Chapter 3 in showing that hardtops of the 1968-76 era had significantly lower roof crush resistance than sedans, even after adjusting for car size, whereas hardtops of the 1964-67 era were as strong as sedans.

4.1 Data preparation

The National Accident Sampling System (NASS) files [68], [69], [75] for 1982-86 have uniform definitions for the variables that will be used in the analysis. Vehicles are selected if the general area of damage in the primary Collision Deformation Classification (CDC) [8] is to the top of the vehicle (GAD1 = T). The vehicles have to be passenger cars other than convertibles (BODYTYPE = 2-9) and must not be driven from the scene (TOWAWAY = 2-4). The roof damage extent zone has to be known (EXTENT1 = 1-9). NASS uses a convenient 4 digit make model code similar to the Fatal Accident Reporting System (FARS) [17]. Although NASS cases are selected for investigation by a complex weighted sampling scheme, the data are treated here as a collection of simple unweighted accident cases. (As a check, the analyses of this chapter were repeated with Ockham weighted [75] NASS data and weighted NCSS data; the trends were virtually identical to those with unweighted data.) NASS contains cars of model year 1987 all the way back to the distant past; the data, however, get sparse before model year 1970.

The National Crash Severity Study (NCSS) data [76], collected in 1977-79, uses a CDC which, for the purpose of the analyses of this chapter, is identical to NASS. Towaway passenger cars other than convertibles (VBDYSTY = 1-2) are selected if the general area of damage in the primary CDC is to the top of the vehicle (VGADPR = T). The roof damage extent zone has to be known (VEXTEP = 1-9). NCSS' 5 digit make model code is translated to the 4 digit FARS code. Although NCSS cases were selected for investigation by a complex weighted sampling scheme, the data are treated here as a collection of simple unweighted accident cases. NCSS contains cars of model year 1978 and earlier years; the data get sparse before model year 1965.

The Multidisciplinary Accident Investigation (MDAI) file [9], [65] accrued throughout 1967-78, but above all during 1971-73. The CDC is the same as in NCSS. Passenger cars other than convertibles (V124 = 1-5) are selected if the primary CDC has top damage (V144 = 5). The roof damage extent zone is known in every case. MDAI uses the same 5 digit make model code as NCSS and it is translated to the 4 digit FARS code. MDAI is not a probability sample of crashes and, in particular, is skewed toward more severe crashes and injuries. But it can reasonably be assumed that the bias toward more severe crashes is not stronger for one model year or vehicle type than for others [74]. MDAI contains cars of model year 1978 and earlier years; the data get sparse before model year 1965, but the combined data of MDAI, NCSS and NASS yield an adequate sample of cars of the mid 1960's.

One important data element for the analysis is the presence or absence of upper B pillars. On the MDAI file, it is explicitly and accurately coded (V124), based on actual observation of the cars. In NCSS and NASS, it has to be inferred from the VIN, using a program developed in NHTSA's evaluation of side door beams [49], p. 229. The program is tricky because, during the 1970's manufacturers sometimes called cars "hardtops" even though they had upper B pillars. In a few cars, a determination could not be made from the VIN alone; those cases were not used.

Car size variables such as track width, curb weight, wheelbase and height are needed for the analyses that follow. Values are appended from Automotive News Almanacs [2] rather than taken directly from the data files, so as to assure uniform definitions across files.

The pooled data set of NASS, NCSS and MDAI cases contains 1938 rollovers of model years 1964-82 with known B pillar status. About 1000 of the cars are from NASS, 500 from NCSS and 400 from MDAI.

The key dependent variable in the analysis is the CDC extent zone of roof crush in the passenger compartment area. The extent zone is a numeric, ordinal variable with possible values 1-9. SAE Recommended Practice J224a MAR80 [8] defines the zones as follows:

1	Surface scratching and abrading
2	Vertical distance between the top surface and the side rail
3-5	3 equal zones determined by dividing the vertical height of the side glass by 3
6-8	3 equal zones determined by dividing the vertical distance between the base of the side glass opening and lower edge of the rocker panel by 3
9	Crush extending below the level of the rocker panel

Although extent zone is limited to integer values, it essentially represents a continuous variable, since extent zones could be subdivided into smaller zones, if desired. Given the essentially continuous character of the variable, its limited range (1-9) and fairly uniform distribution within that range, it makes sense to calculate simple arithmetic averages of the extent zones for groups of cases - e.g., it makes sense to say, "these 10 cars have an average extent zone of 3.5."

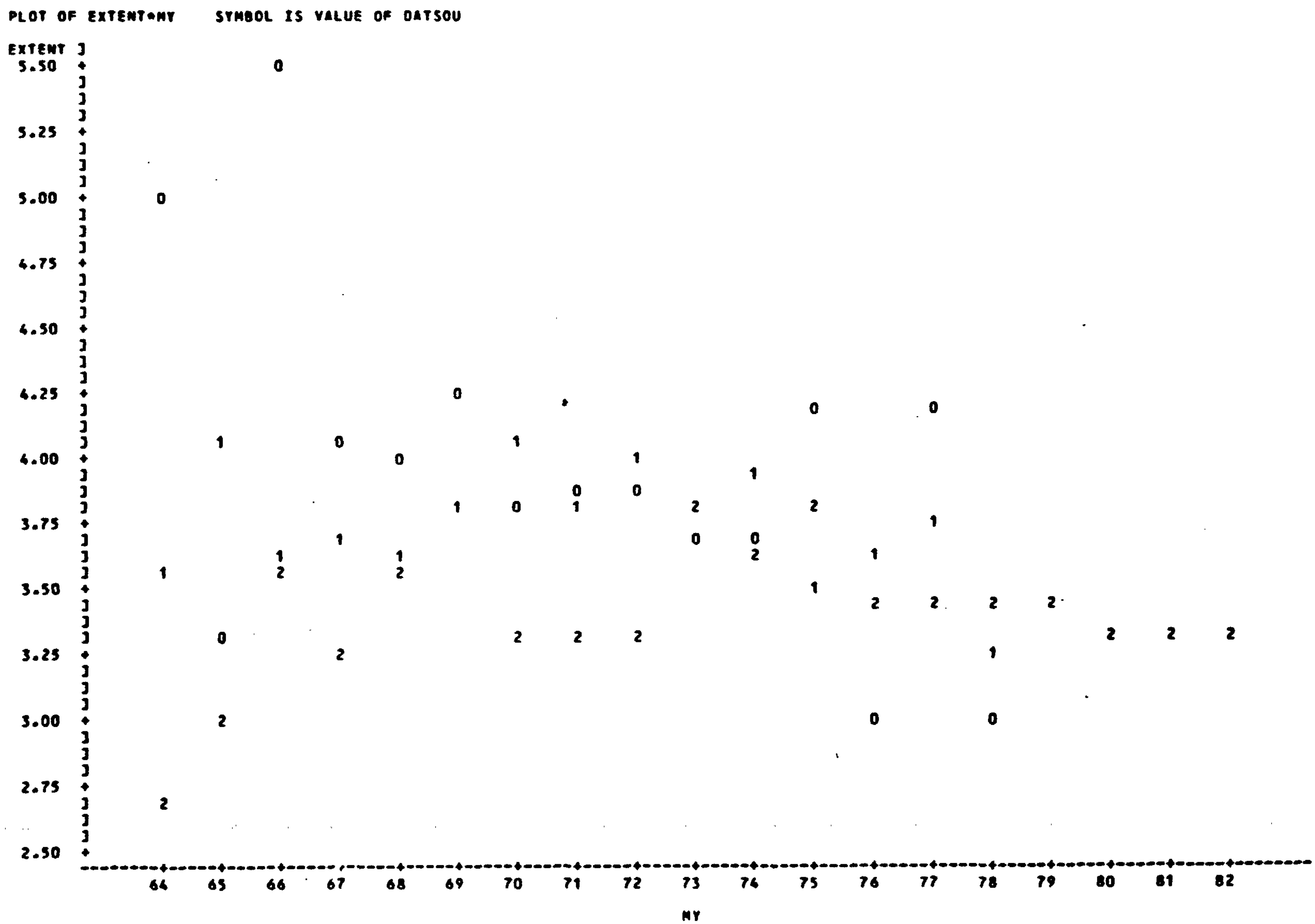
4.2 Biases due to data source and vehicle size

The pooling of 3 separate data sources is needed for an adequate sample size, especially in the earlier model years, but it raises an obvious concern about the compatibility of the data. It is especially a matter of concern when one of the files is not a probability sample and, in the other two, weighted sample data are treated as unweighted cases; also, when two of the files go only as far as 1978 while the third is sparse in the early years.

Figure 4-1 is a graph of the average roof crush extent zone by model year and data sources. The average values of the MDAI cases are shown as 0's on the graph, the NCSS averages as 1's and the NASS results as 2's. There is a lot of fluctuation from year to year due to small sample sizes, especially for MDAI and NCSS, which have smaller samples than NASS. Nevertheless, it is clear that NASS crush levels, which average mostly between 3.25 and 3.75 zones, are usually lower than MDAI and NCSS, which typically average between 3.5 and 4.25. NASS cases are of lower severity, on the average, because the weighted sampling scheme calls for less oversampling of severe crashes than NCSS. MDAI appears to be slightly higher than NCSS, but the difference is not as clear as with NASS. Obviously, it will be necessary to adjust for the discrepancies between the data files: otherwise, the late model years, which are exclusively NASS data, would be given unfairly favorable ratings while the cars of the 1960's would appear worse than they really are.

One major finding of the evaluation, stressed throughout

FIGURE 4-1: AVERAGE ROOF DEFORMATION EXTENT ZONE BY MODEL YEAR AND DATA SOURCE
(0 = MDAI 1 = NCSS 2 = NASS)



NOTE: 2 OBS HIDDEN

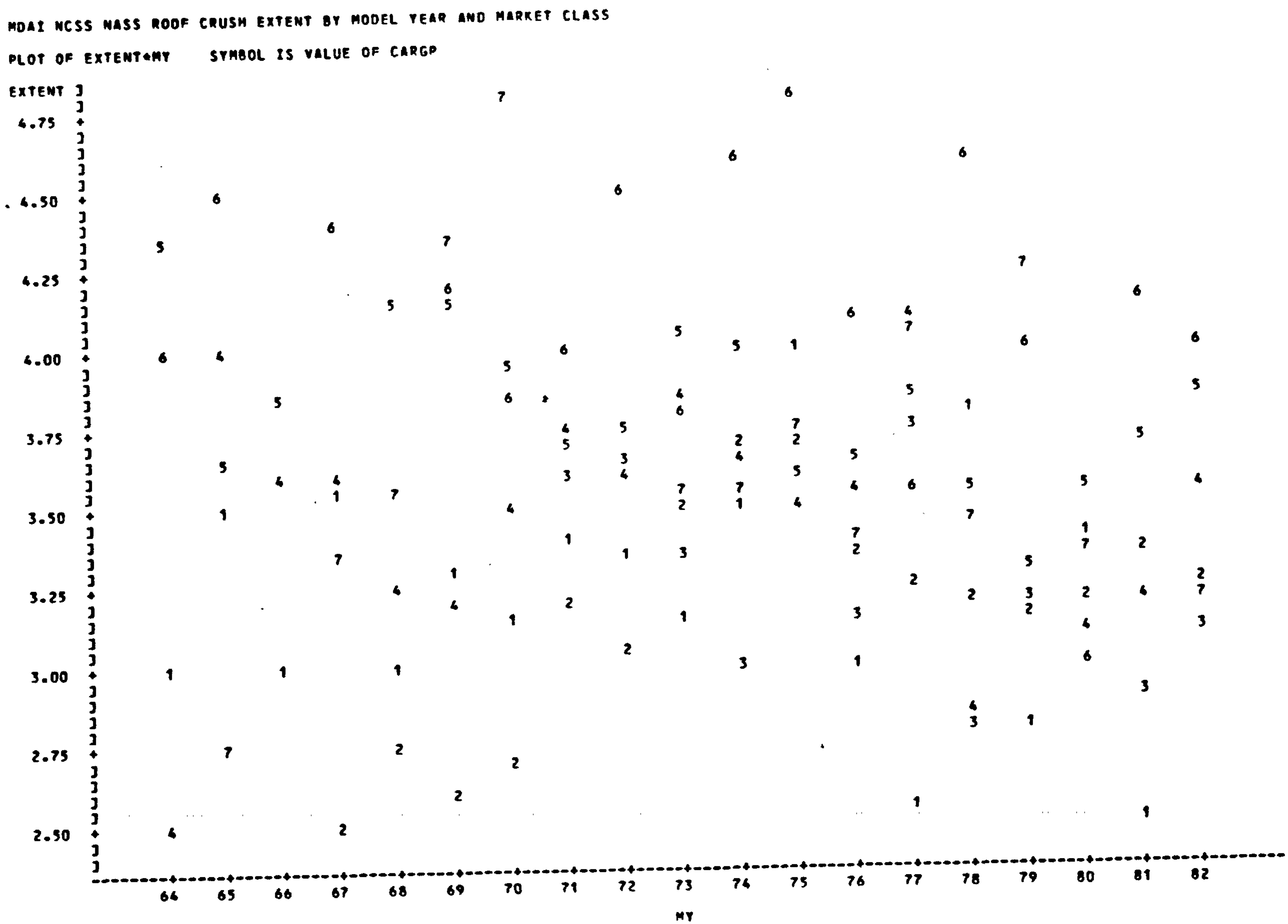
Chapters 5-7, is that it takes less force to roll over a small, narrow car than a large, wide one. As a result, the rollover crashes of small cars are on the average less severe (although a lot more frequent) than the rollovers of large cars. Thus, small cars would be expected to have lower average roof damage than large cars even if the "intrinsic" roof strength of small and large cars were the same - because the small cars are in less severe crashes. A good way to study the effect of car size on roof crush is to use the 7 market classes defined in detail in Section 5.4. These classes are

1. Volkswagens
2. All imports other than Volkswagens
3. Domestic subcompacts
4. Domestic compacts
5. Domestic intermediates
6. Large domestic cars
7. Sporty domestic cars

Figure 4-2 is a graph of the average roof crush extent zone by model year and market class. As expected, large cars (class 6) consistently have the highest average roof crush, usually averaging zone 4 or worse. (Since large cars tend to be slightly taller than small cars, their crush zones are slightly larger; if crush had been measured in inches rather than zones, the effect for large cars might have been even worse.) Intermediates (class 5) are just below large cars. Small cars such as Volkswagens, other imports and domestic subcompacts (classes 1-3) are consistently at the lower end of the graph, with roof crush averaging about 3 zones.

Small cars account for a much larger proportion of sales in the late 1970's and early 1980's than in the 1960's. Since small cars have less severe rollovers than large cars, this introduces a bias into the

FIGURE 4-2: AVERAGE ROOF DEFORMATION EXTENT ZONE BY MODEL YEAR AND MARKET CLASS - OBSERVED, UNADJUSTED DATA



NOTE: 10 OBS HIDDEN

analysis of roof crush by model year - the later model years will have lower average roof crush because the cars are smaller, not necessarily because roofs became stronger.

4.3 A model which adjusts for data source and vehicle size

The first step in developing a model which filters out the biases due to data source and car size is a linear regression of the roof damage extent zone by data source and a number of car size variables. The regression does not include the full data set but is limited to model years 1970-77, where there are ample numbers of cases from MDAI, NCSS and NASS in each year (see Figure 4-1). The regression is further limited to cars with upper B pillars, so as to keep out any effect of hardtops vs. sedans. The effect of the B pillar, as noted in Section 3.7, is not a "bias" that needs to be filtered out but one of the key effects that the model is supposed to measure - but since hardtops tend to be larger, on the average, than sedans, the effect of the B pillar could become confused with car size effects unless hardtops are kept out of the regression. (A similar approach is used in Section 6.2.)

The data points in the regression are the 781 individual cases of model year 1970-77 sedans. Data source is a categorical variable with values MDAI, NCSS and NASS. Several combinations of car size variables were tried. The variables included market class (categorical, with 7 categories as defined above); track width, curb weight, wheelbase and car height (all linear, measured in inches or pounds). The dependent variable is the actual, observed damage extent zone.

Track width was the only car size variable that had a significant effect in this relatively small data set. In particular, the market class variable had little effect in regressions that included track width. The best regression model, then, included only data source and track width. The regression coefficients are:

Intercept	+0.0661
MDAI	+0.1824
NCSS	+0.1481
Track width	+0.0602

The coefficient for NASS is implicitly zero. Essentially, the model says that MDAI and NCSS cases have higher average damage extent than NASS cases of cars of the same size and model year, by .18 and .15 zones, respectively. Wider cars have more severe damage than narrow ones (because they roll over only in more severe crashes); an extra inch of track width adds .06 zones to the damage extent. R squared is .034, a significant correlation, although much lower than any other R squared in this report. So low a value of R squared is permissible here, for several reasons. Above all, the regression is based on individual rather than grouped cases. The principal reasons for differences in damage extent between individual cases are that the crashes are of different severities. The objective here is not to predict the damage in individual cases but only to determine the [minor] extent to which the damage is influenced by data source and car size.

The next step is to use the regression coefficients to adjust damage extent by track width and data source. For the full data set including model years 1964-82 and hardtops as well as sedans, define

Adjusted damage extent zone =

Actual damage extent zone + 3.561 - .0602 Trackwidth - .1824 if data=MDAI
.1481 if data=NCSS

Note that the formula filters out the effects identified by the regression for data source and track width, which had been biasing the results. The constant of 3.561 is added to assure that the adjusted extent of damage has the same average values as the observed extent.

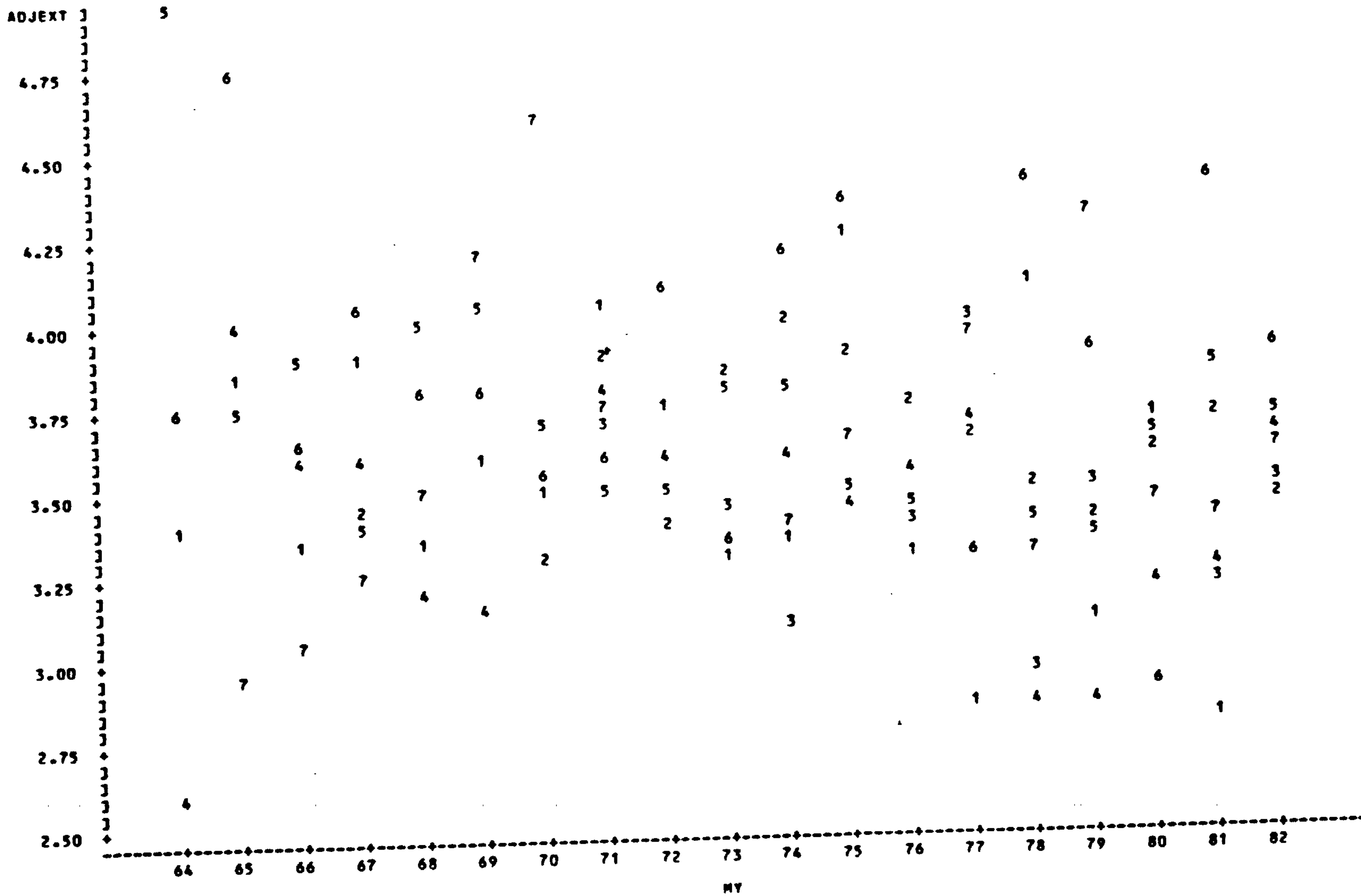
Figure 4-3 is a graph of the adjusted average roof crush extent zone by model year and market class. It is intended for comparison with Figure 4-2, which shows the unadjusted averages. The adjustment procedure does a good job scrambling the results for market classes 1-5 (small to intermediate size cars), indicating good control for car size. But full size cars (class 6) still tend to have consistently the highest roof crush, although not by as large an extent as in the unadjusted data. That is consistent with the findings of Chapter 3 that large cars had weaker roofs than other makes and models (although another possible explanation for the observed effect is that crush has a nonlinear relationship with the car size parameters).

Figure 4-4 shows the adjusted average roof crush zone by model year and body style. True hardtops without upper B pillars are shown as 0's on the graph, while the averages for cars with B pillars are graphed as 1's. Although there is a fair amount of fluctuation due to small samples, a remarkable pattern is evident. During model years 1964-67,

FIGURE 4-3: AVERAGE ROOF DEFORMATION EXTENT ZONE BY MODEL YEAR AND MARKET CLASS – ADJUSTED FOR DATA SOURCE AND CAR SIZE

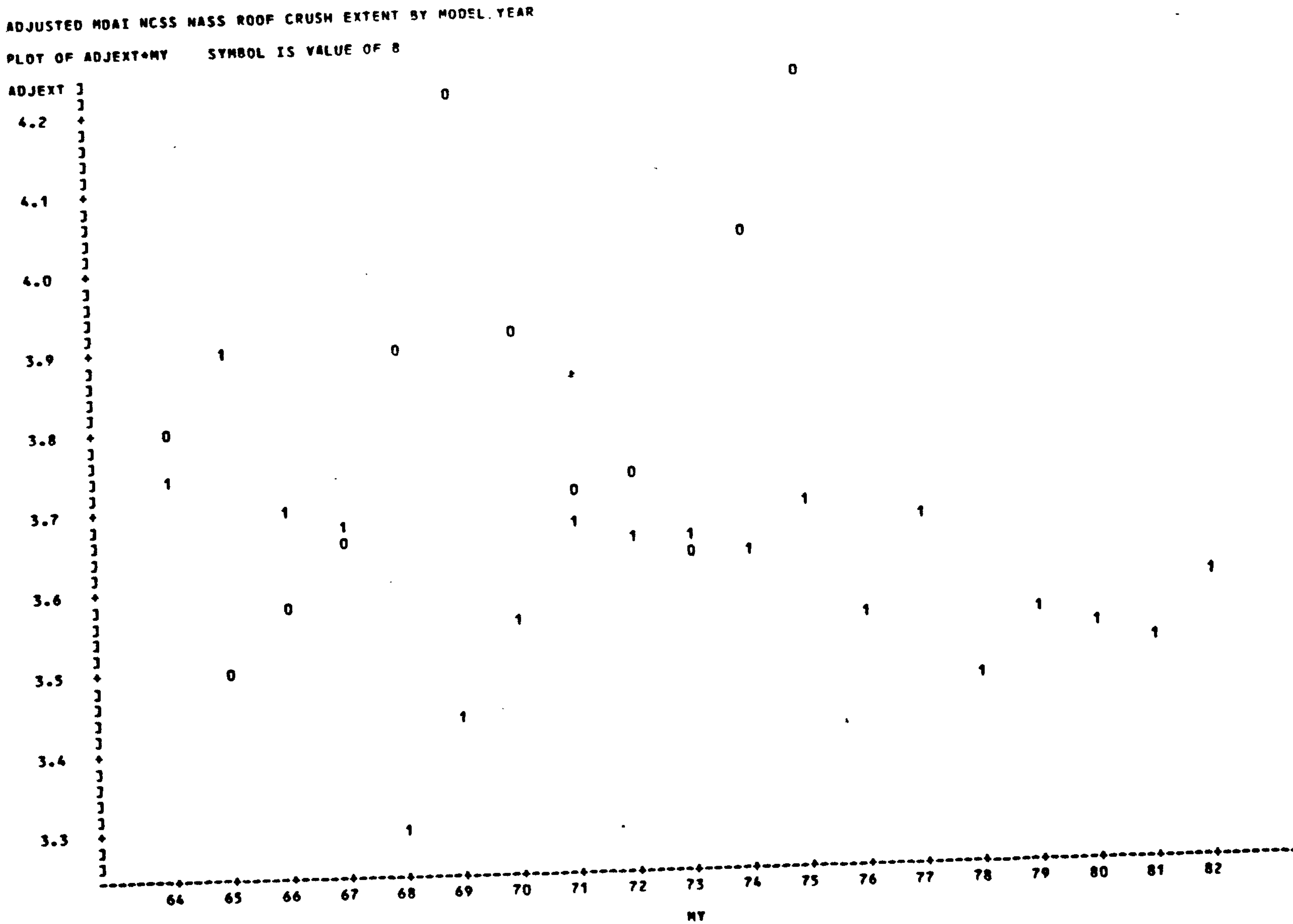
ADJUSTED NDAI NCSS NASS ROOF CRUSH EXTENT BY MODEL YEAR

PLOT OF ADJEXT*MY   SYMBOL IS VALUE OF CARGP



NOTE: 18 OBS HAD MISSING VALUES   11 OBS HIDDEN

FIGURE 4-4: AVERAGE ROOF DEFORMATION EXTENT ZONE BY MODEL YEAR AND BODY TYPE – ADJUSTED FOR DATA SOURCE AND CAR SIZE
(0 = true hardtop; 1 = sedan, coupe, pillared hardtop, etc.)



there is little difference between hardtops and sedans. In 1968-75, hardtops have more crush than sedans in 7 out of 8 years: even by a nonparametric test, hardtops are significantly worse than sedans. After model year 1975, few hardtops were produced. The average crush for sedans remained relatively constant throughout model years 1964-82, with a possible slight decrease after 1975. The difference between hardtops and sedans (at least after 1967) is far greater than any change within the sedans.

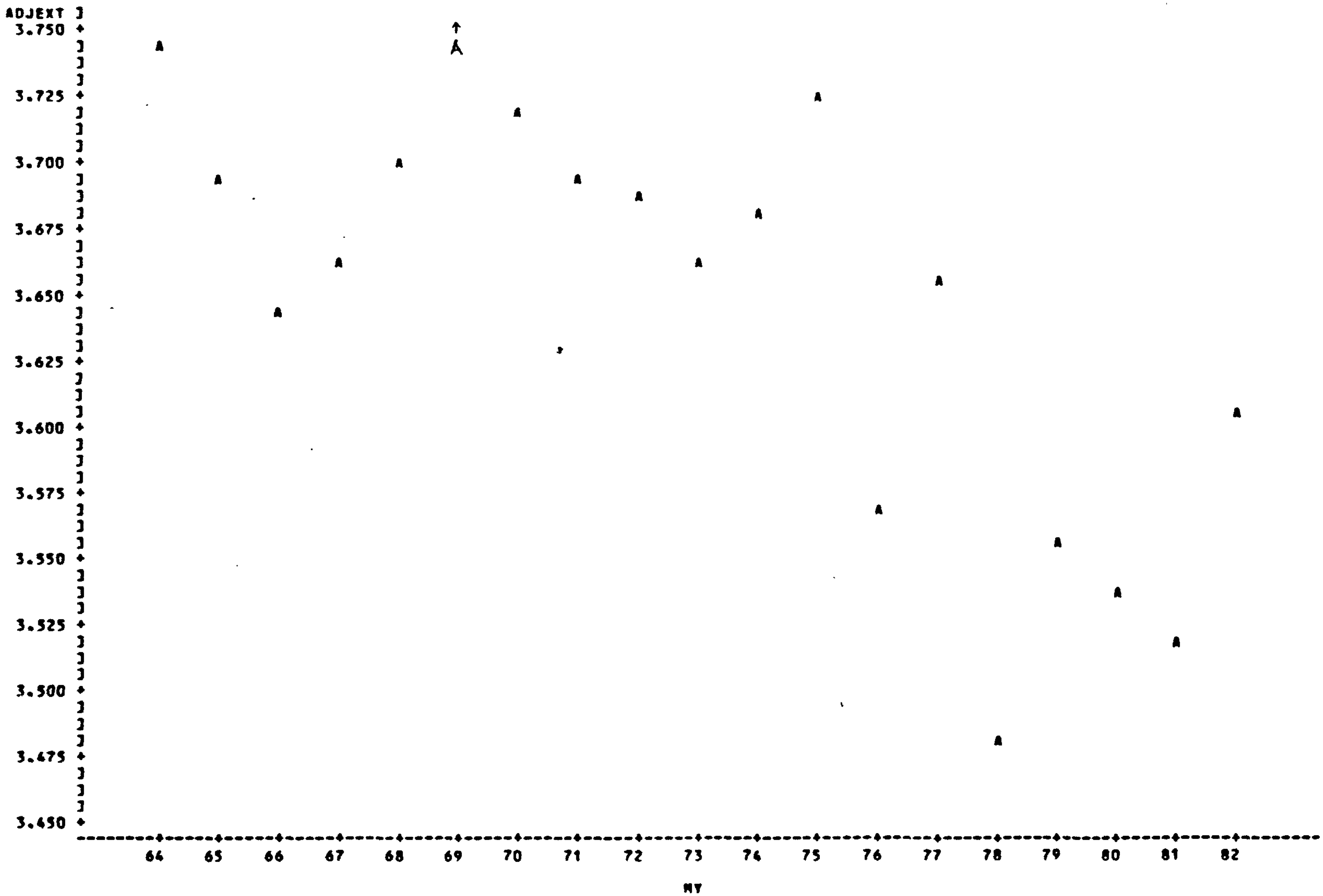
Finally, Figure 4-5 shows the average for all cars of the adjusted roof crush extent zone, by model year. Although it is difficult to locate exactly when the improving trend started, there is no question that cars of the later 1970's and early 1980's had less roof crush in actual crashes than cars of the later 1960's, even after adjusting for car size. But the magnitude of the improvement is small in practical terms. Average roof crush was about 3.7 zones in model years 1964-74 and about 3.54 zones in model years 1977-82. According to SAE Recommended Practice J224a MAR80, extent zones 3-5 divide the vertical height of the side window into 3 equal zones; for a typical side window height of 15 inches, that means each zone is about 5 inches wide. An average reduction from 3.7 to 3.54, or 0.16 zones corresponds to approximately 0.8 inches reduction in average crush.

The analysis confirms the test results of Chapter 3 in showing that hardtops of the 1968-76 era had significantly lower roof crush resistance than sedans, even after adjusting for car size, whereas

FIGURE 4-5: AVERAGE ROOF DEFORMATION EXTENT ZONE BY MODEL YEAR - ADJUSTED FOR DATA SOURCE AND CAR SIZE

ADJUSTED MDAI NCSS NASS ROOF CRUSH EXTENT BY MODEL YEAR

PLOT OF ADJEXT*MY   LEGEND: A = 1 OBS, B = 2 OBS, ETC.



hardtops of the 1964-67 era were as strong as sedans. It confirms the finding of Chapter 3 that roof strength of sedans changed little during the 1964-82 era. The abolition of true hardtops was a major reason that roof crush strength improved in the mid 1970's.

CHAPTER 5

ROLLOVER PROPENSITY BY MODEL YEAR: ANALYSES OF TEXAS DATA

Texas accident data for calendar years 1972-74 and 1977-83 were tabulated by model year to see if the rollover propensity of passenger cars changed significantly between model years 1963 and 1982. Initial analyses suggest that rollover propensity varied greatly during those years; for example, it was about 45 percent higher for 1980-82 cars than 1969-72 cars. More detailed analyses show that rollover propensity is highly correlated with the size and weight of cars. Specifically, the higher the track width, curb weight and wheelbase, the lower the rollover propensity. In fact, adjustment of rollover rates by track width and curb weight and wheelbase removes much of the variation during model years 1963-82 and across car lines. The only exception is the pre-1969 Volkswagen Beetle, which had even higher rollover rates than would be expected for a car of its size and weight.

5.1 Analysis objectives and approach

The objective of the analysis, as stated in Section 1.4, is to compare the intrinsic rollover propensity of cars of different model years: to track the trend from model year 1963 to 1982. As a minimum, measures of "intrinsic" rollover propensity should filter out influences other than the design of the vehicle. They should not be affected by what type of people drive the vehicle nor by year to year changes in driving patterns or accident reporting methods. At a deeper level, the measures should also filter out the effect of changes in vehicle design that were not made primarily for safety reasons but rather in response to external circumstances such as consumer preferences, fuel prices, etc. Specifically, the model should control for the size and weight of the car.

A prototype for the analysis may be found in NHTSA's evaluation of occupant protection in frontal interior impacts [47], Chapter 4. There, the objective was to display frontal fatality risk as a function of model year. Nonvehicle factors were filtered out by limiting the analysis to head-on collisions. An initial "simple" model computed the relative risk of two model years, say 1970 and 1980, by looking at the fatality ratio in head-on collisions of 1970 cars with 1980 cars. A subsequent model "adjusts" the ratio for differences in the weights, etc., of the cars of different model years.

A unique advantage in the evaluation of frontal interior impacts was the opportunity to use head-on collisions, where cars of two different model years are in the same crash. That by itself filtered out nonvehicle factors such as crash involvement rates, reporting rates, etc. Unfortunately, since most rollovers are single vehicle crashes, that approach cannot be used here. Instead, the principal method for controlling driver and exposure differences is to express "rollover propensity" as the <u>ratio</u> of rollovers to <u>frontal</u> impacts with fixed objects.

Whereas it has been customary to express "rollover propensity" as a ratio of rollovers to a control group consisting of other types of single vehicle crashes (see Section 2.1 and [33], [36], [37], [45], [90]), this report differs by limiting the control group to frontal single vehicle crashes. There is a practical and an intuitive reason for limiting the control group to frontal crashes.

The practical reason is that a fatality risk index by model year for frontal impacts was calibrated in a previous NHTSA evaluation [47], Chapter 4. The ratio of rollover fatalities to deaths in frontal fixed object impacts, multiplied by the frontal risk index, yields an absolute fatality risk index for rollovers by model year (see Section 6.2). Since a comparable risk index for nonfrontal fixed object impacts does not yet exist, this approach could not be used if the control group included single vehicle crashes other than frontals.

The intuitive reason is that frontal impacts with fixed objects come closest to being a "control" group for the purpose of this study. They control for driver and exposure differences but <u>not</u> for vehicle differences. Specifically, there are many factors that affect the number of rollovers per 1000 car years, for a particular make/model:

Exposure factors: number of miles driven per year

Environmental factors: items situated parallel to the roadways where these cars are driven (ditches, loose dirt, trees, guard rails, etc.); road conditions (slippery pavement, curves, etc.)

Driver factors: frequency of inattentive, unskilled, aggressive, or inexperienced driving - activities likely to result in off-road excursions

Vehicle factors:

Directional stability: a directionally unstable car tends to skid or spin out of control or be hard to steer on course, resulting in off-road excursions into loose dirt, ditches, etc., where rollover is likely to occur

Rollover stability: tendency of a car to remain upright _given_ that it has come in contact with a typical off-road tripping mechanism such as loose dirt or a ditch

As stated in the Summary and Section 1.5 of this report, the measure of "rollover propensity" should combine the effects of directional stability and rollover stability (the vehicle factors) but should exclude or control for exposure, environmental and driver factors. For a particular make/model, the number of frontal impacts with fixed objects per 1000 vehicle years would appear to be strongly influenced by exposure (the more mileage, the more involvements) and driver factors (inattentive, unskilled, aggressive or inexperienced driving - i.e., the same types of behavior that result in rollovers) but only to a lesser degree by vehicle factors such as directional stability or rollover stability [60]. Thus, fixed object frontals are an appropriate control group. By contrast, the risk of other types of single vehicle crashes, such as side impacts with fixed objects, may be strongly influenced by a car's directional stability [60]. Including them in the control group may result in a partial "control" for directional stability in addition to driver factors. That would be contrary to the goal of this report, a rollover propensity measure combining directional and rollover stability (although it might be suitable in other studies which concentrate primarily on rollover stability).

Examination of sales and accident data confirms that frontal impacts with fixed objects are a suitable control group. For the arbitrarily chosen model years 1972, 73, 79 and 80, the "shares" of new car sales [2] and fatalities to date for 7 market classes of cars (defined in detail in Section 5.4) are as follows:

	Sales	Frontal/ Fixed Object	Side/ Fixed Object	Roll-overs
Volkswagens	2.9	2.7	2.9	3.8
Other imports	17.6	17.0	16.8	26.7
Domestic subcompacts	11.0	11.3	11.3	11.6
Compacts	14.1	12.3	15.1	14.9
Intermediates	22.6	23.5	22.1	18.1
Large cars	27.0	22.8	19.0	14.7
Sporty domestic	5.1	10.0	12.8	10.4
	100	100	100	100

Only one group has a share of frontal fixed object fatalities that differs greatly from its share of sales: the sporty domestic cars (Mustang, Camaro, Firebird, etc.). There is little doubt that these cars have an exceptionally young and aggressive driving clientele, so it is appropriate that they should have a high share of frontal impacts with fixed objects. The other 6 classes have a more normal mix of drivers and relatively little difference between the sales and frontal fatality shares. The sporty cars have an even higher share of side impacts with fixed objects (12.8) than frontals (10.0), suggesting a possible directional stability problem. Their 10.4 percent share of rollovers is higher than their share of sales (5.1) and frontals (10.0), but lower than their share of side impacts (12.8). In other words, sporty cars have a very high rollover rate per million car years and a moderately high rollover propensity (as defined in this report). Even though they have excellent rollover stability (as evidenced by the low ratio of rollovers to side impacts and as might be expected for these low-slung, wide cars) their net rollover propensity is high, perhaps because of low directional stability.

Excluding the sporty cars, the "shares" of new car sales and fatalities to date for the remaining 6 market classes are as follows:

	Sales	Frontal/ Fixed Object	Side/ Fixed Object	Roll-overs
Volkswagens	3.0	3.0	3.3	4.2
Other imports	18.5	19.0	19.3	29.8
Domestic subcompacts	11.6	12.6	13.0	12.9
Compacts	14.8	13.7	17.3	16.6
Intermediates	23.7	26.2	25.3	20.2
Large cars	28.4	25.4	21.8	16.4
	100	100	100	100

For these 6 classes, there is remarkably close agreement between vehicle sales and share of frontal fixed object fatalities. Most important, there is little vehicle size effect. Intermediates are slightly overrepresented (presumably because they include cars like Monte Carlo and Grand Prix, bringing in a more aggressive group of drivers) while full-sized cars are slightly underrepresented (they have the least aggressive drivers [87], Table 10). There is a modest vehicle size effect for side impacts with fixed objects: the two biggest car groups have a smaller share of side impacts than frontals, while the 4 smaller car groups have larger shares; the result is consistent with studies indicating that large cars, on the average, have better directional stability than small cars [60]. There is a much stronger vehicle size effect for rollovers: the rollover stability of large cars, in combination with their directional stability, yields a low net "rollover propensity" as defined in this report.

Actually, the dependent variable in the regressions of this chapter and the next one is not the ratio itself but the log of the odds ratio of rollovers to fixed object impacts. In other words, they are logistic regressions on aggregate data, similar to those in NHTSA's evaluation of frontal interior impacts [47], pp. 143-153. Using the log of the odds ratio has several advantages. It tends to have a more nearly linear relationship with independent variables than does the odds ratio itself (higher R squared). Residual error tends to be constant (desirable for regression models) rather than proportional to the dependent variable (undesirable).

5.2 Data preparation, key variables and calendar year correction

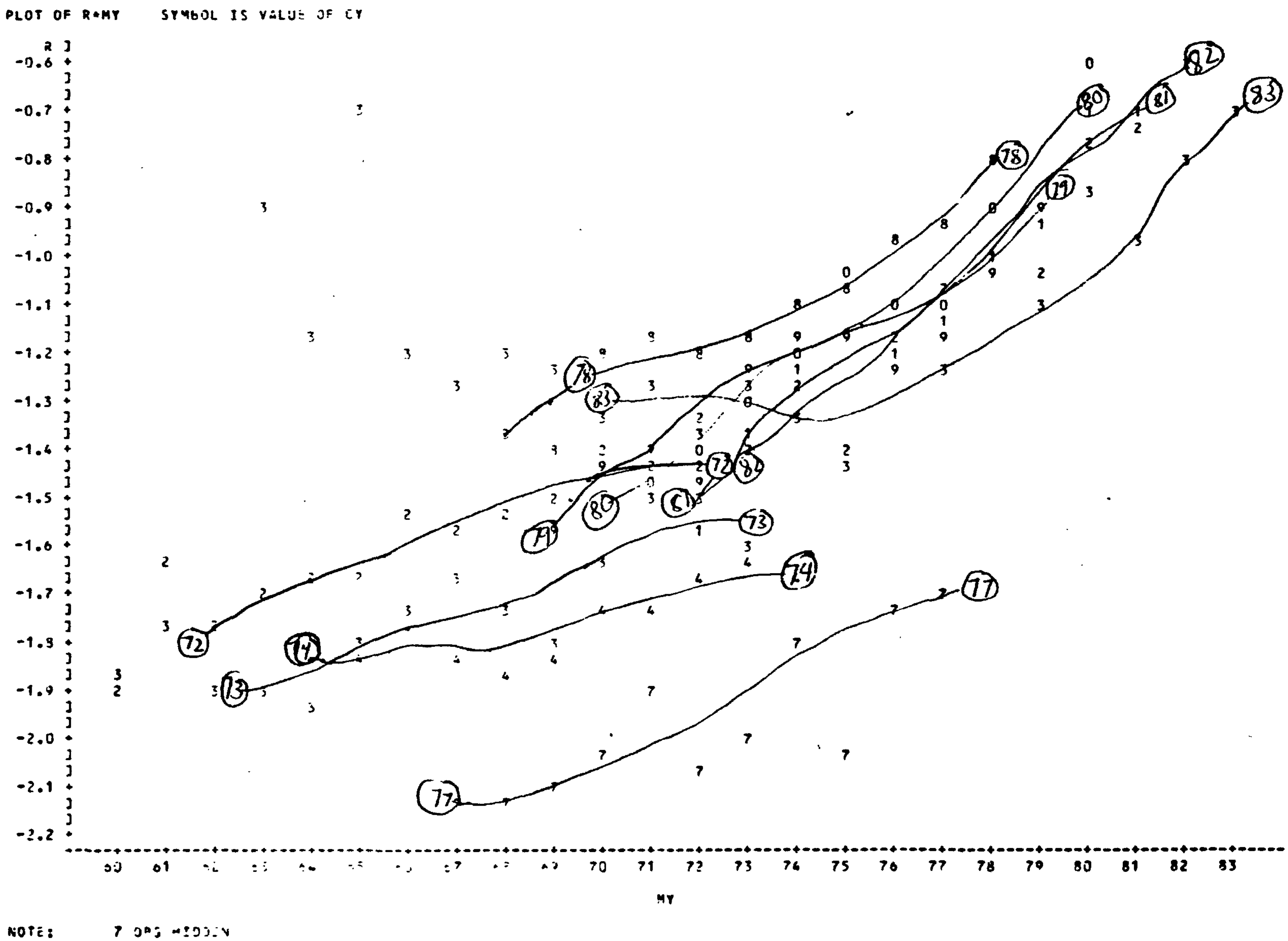
Texas data [64] are used because they are the only State data available at NHTSA meeting all the prerequisites for the analysis: files are available as far back as 1972, providing information on cars of the 1960's. Vehicles are identified by make, model and body style. Damage location (frontal or side) and rollover occurrence are coded, with few missing data. Texas files are also advantageous because of their large size.

In the analyses of Texas data, a "rollover" is any crash involved passenger car whose first harmful event was an overturn (FHE = 0) or the Object Struck was coded 1 (vehicle overturned) or the damage codes were LT, RT or TP (top of the car). A "frontal impact with a fixed object" is any car, other than the above, in a single vehicle accident (TOT_VEH = 1), with damage codes FC, FD, FL or FR (front of the car), but excluding collisions with pedestrians or pedalcyclists (FHE = 1 or 5). "Passenger cars" include coupes, sedans, hardtops and station wagons (VEH STY = 1-6), but convertibles are excluded in this analysis as well as in later chapters. In NHTSA's versions of the 1982 and 1983 Texas files, cars with make model codes over 255 had to be deleted due to coding errors. The 1972-74 and 1977-83 Texas files, which were available to NHTSA, contain approximately 35,000 records of passenger cars that rolled over and 110,000 cases of cars that hit fixed objects without rolling over.

The first step in the analysis is to tabulate the rollovers and fixed object impacts by calendar year and model year and to graph the log of the odds ratio of rollovers to fixed object impacts by model year and calendar year, as shown in Figure 5-1. The dependent variable in Figure 5-1 is LOGR, the log odds ratio; the independent variable is the model year; and the various curves depict the relationship of the two variables for different calendar years of Texas data. With ideally "clean" data, the log odds ratio would depend only on the model year and not on the calendar year, and the curves should coincide. Figure 5-1, however shows some obviously significant calendar year effects. For example, in 1977, the ratio of rollovers to fixed object impacts is substantially lower than in other years, while in 1978 it is the highest. Calendar year effects are most likely due to differences in the ways that crash data were reported and encoded, although there might also be some genuine effects (e.g., more rollovers in 1972, before the 55 mph speed limit).

Figure 5-1 also shows an increase in LOGR in the later model years. That appears, at first glance, to be consistent with the trend toward smaller, narrower cars. But the results need to be viewed with caution because the age effect may be at work. In any single calendar year, the later model years are also newer cars. If newer cars, due to nonvehicle factors such as the driver or the roadway exposure mix, tend to

FIGURE 5-1: REPORTED LOG ODDS RATIO OF ROLLOVERS TO FRONTAL FIXED OBJECT IMPACTS, BY MODEL YEAR AND CALENDAR YEAR



have more rollovers relative to fixed object crashes, that could partly explain the trend shown in Figure 5-1. Also, driver unfamiliarity with new cars may lead to directional control problems and, as a result, more rollovers [78].

Thus, there may be up to three factors at work: the genuine model year trend due to changes in vehicles, the calendar year effect and the age effect. The analysis must discard the latter two and isolate the first. That is hard to do because there is a direct relationship between model year, calendar year and vehicle age.

The next step is to calibrate the calendar year and age effects in a regression which does not include the model year variable. Instead, the regression should include <u>key variables</u> that describe the vehicle: its track width, curb weight and wheelbase (see Sections 1.5 and 2.1). This initial regression only serves the purpose of calibrating the CY and age effects, not to explain the effects of the key variables on rollover propensity. The Texas data are tabulated by calendar year, model year and make/model code. For each model year and make/model combination, the key variables (track width, curb weight, height and wheelbase) are derived from Automotive News Almanacs [2] and are listed in Appendix B. The "track width" is the average of the front and rear track widths. The height of the center of gravity would also have been a desirable variable, but it is unknown for most of the cars. Actually, for passenger cars, the c.g. height is usually close to 21 inches and has a much narrower range than the other key variables [35].

The regression is limited to cars of model years 1968-76. As can be seen in Figure 5-1, this is the middle range of model years where data from the various calendar years overlap. It is also a relatively uniform set of cars: after the major safety standards but before downsizing. That will help avoid biases in the analyses - e.g., attributing a high rollover rate to the latest calendar years, because they are rich in downsized cars. The 1968 Volkswagen Beetle is also excluded from the regression, because it may have a higher rollover rate than explained by the key variables, biasing the analysis (see Section 2.2). So are cars more than 12 years old. Figure 5-1 shows that the age effect, if any, appears to reverse direction beyond age 12 or so, requiring a nonlinear age term if the old cars are included. That is a needless complication because the sample contains few old cars; only 1972, 73 and 83 Texas data code the model years of cars more than 10 years old.

The data are grouped by calendar year (a categorical variable with values 72, 73, 74, 77, 78, 79, 80, 81, 82, and 83) and by class intervals of vehicle age (0-2, 3-5, 6-8, 9-12 years), track width (45-47, ... , 64-66 inches), curb weight (1600-2399, ... , 4800-5599 pounds), and wheelbase (70-87, ... , 128-135 inches). Thus, the model year variable is eliminated from the regression. The dependent variable is LOGR, the log of the odds ratio of rollovers to fixed object impacts. The independent variables are calendar year (categorical) and age, track width, curb weight, and wheelbase (all continuous; the values used are the midpoints of the class intervals). There are 416 data points. The data points are weighted according to the number of rollover cases in that group.

In the regression, each of the independent variables had a significant effect except wheelbase. As a result, it became possible to eliminate the wheelbase variable from the model. This does not necessarily imply that wheelbase is unimportant as a rollover propensity factor, merely that it is not needed for calibration of the calendar year and vehicle age correction terms. The accident cases were regrouped by the remaining variables, calendar year, age, track width and curb weight, condensing them to 278 regression data points. The regression coefficients are:

INTERCEPT	5.24	TRACK WIDTH	- .091
CURB WEIGHT	- .00024	VEHICLE AGE	- .027

CY72	-.444	CY77	-.788	CY80	.044
CY73	-.585	CY78	.017	CY81	-.019
CY74	-.647	CY79	-.096	CY82	-.021

The CY83 term is implicitly zero, since the terms for the other calendar years are measured relative to 1983. R squared is .93, an excellent correlation. Essentially, the model says that rollovers were sharply underreported (or less common, or both) in calendar years 1972-77 relative to 1978-82.

It is worthwhile to compare the model's regression coefficients to the visual information of Figure 5-1. Clearly, the model is right in putting CY73, 74 and especially 77 well below the other years. It is surprising, though, that the model gives a large negative coefficient to CY72, while Figure 5-1 puts the curve for 1972 more or less in the pack. Similarly, the model does not give CY78 as large a positive coefficient as expected. That is because the model gives a rather strong negative coefficient to vehicle age. It says the curve for 1972 fits into the pack just because the MY 1968-72 cars were still new in CY 1972, but if they had been old, the curve would be well below those for calendar years 1978-83.

From Figure 5-1, it is hard to guess whether the age effect has been correctly calibrated by the preceding model or whether there is still, despite the precautions, some confounding of the age effect with the secular trend toward smaller cars. If so, it might be better to perform the regression without the vehicle age variable. The regression coefficients are:

INTERCEPT	5.17	TRACK WIDTH	- .095
CURB WEIGHT	- .00023		

CY72	-.262	CY77	-.678	CY80	.106
CY73	-.410	CY78	.111	CY81	.025
CY74	-.488	CY79	-.023	CY82	.0005

R squared is .92, still an excellent correlation. These coefficients appear a little more consistent with the visual information in Figure 5-1. Both regressions, however, offer plausible explanations of the phenomena in Figure 5-1 and it is hard to judge which is more accurate. The true effects are probably somewhere in between. Throughout the rest of the report, each analysis of Texas data will be performed twice, once using the first set of regression coefficients as calendar year correction factors, then using the second. That approach will act as a sensitivity test for the calendar year correction; fortunately, it will be seen that the two analyses generally yield similar results.

Finally, the calendar year correction is achieved by dividing the reported number of rollovers by the antilog of the appropriate regression coefficient. For example, suppose that 20 rollovers and 100 fixed object impacts of 1968 Chevrolet Camaros were reported in the 1972 Texas file. The observed log odds ratio of rollovers to fixed object impacts is LOGR = log(100/500) = -1.609. In the regression which included the age variable, the CY72 term is -.444. Thus, if the data had been collected in 1983 instead of 1972, the log odds ratio would have been LOGR2 = -1.609 - -.444 = -1.165 (corresponding to a ratio of 31 rollovers per 100 fixed object impacts). With the set of regression coefficients excluding the age variable, the corrected log odds ratio would be LOGR3 = -1.609 - -.262 = -1.347 (corresponding to a ratio of 26 rollovers per 100 fixed object impacts).

Henceforth, the log odds ratios, after correction with the coefficients from the regression that included the age variable are called LOGR2. Those corrected with the coefficients from the regression that excluded the age variable are called LOGR3.

The calendar year correction factors make it possible to pool data from separate calendar years. For example, suppose that 1978 Toyota Corollas had 20 rollovers and 100 fixed object impacts in 1980 and 25 rollovers and 90 fixed object impacts in 1981. The pooled LOGR2 is the log of [20/exp(.044) + 25/exp(-.019)] / (100 + 90). Thus, LOGR2 = log(44.6/190) = -1.45. Similarly, the pooled LOGR3 is the log of [20/exp(.106) + 25/exp(.025)] / (100 + 90). Thus, LOGR3 = log(42.4/190) = -1.50. The ability to pool data from ten calendar years makes it possible to perform a historical analysis comparing cars over a 20 year period. By eliminating the calendar year terms in any subsequent regressions, it makes it possible to include many other variables.

5.3 A simple model: no control for vehicle size and weight

The analysis now returns to the full Texas data set, including cars of model years 1963-82. Figures 5-2A and 5-2B show the average rollover propensity of cars, by model year. Figure 5-2A is a graph of LOGR2, while Figure 5-2B shows LOGR3 (the two calendar year corrections defined in the preceding section). Both figures show the same pattern. Rollover propensity was low in model year 1963. LOGR2 was -.93, corresponding to 39 rollovers per 100 fixed object impacts; LOGR3 was -1.10, corresponding to 33 rollovers per 100 fixed object impacts.. It rose sharply in the next two years, reaching 39-46 rollovers per 100 fixed object impacts by 1965-66, but it dropped just as fast the next three model years, to a low point of 31-35 rollovers per 100 fixed object impacts in cars of the late 1960's. Rollover propensity increased steadily after 1970 and especially after model year 1976, reaching its highest point in 1980-82 (about 50 rollovers per 100 fixed object impacts). That is about a 40-60 percent increase over the rollover propensity of cars of the 1968-70 era.

Of course, the increase in rollovers after 1970 coincides with the market shift from full sized to smaller cars and the downsizing of cars within market segments. The next task of the analysis is to sort out the effects of vehicle size and weight from other vehicle design factors.

FIGURE 5-2A: LOG ODDS RATIO OF ROLLOVERS TO FRONTAL FIXED OBJECT IMPACTS, BY MODEL YEAR
(Calendar year correction <u>including</u> vehicle age term)

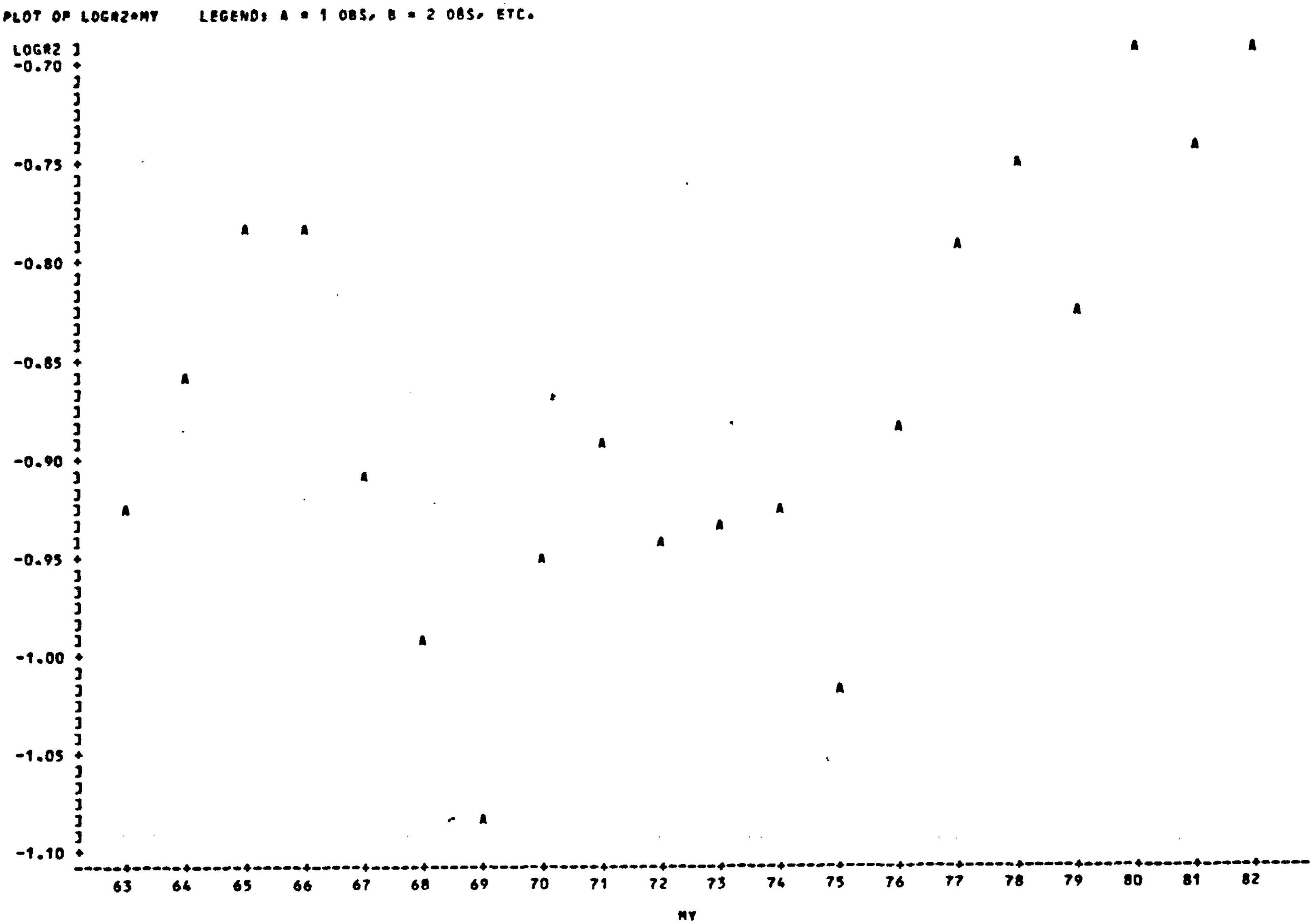
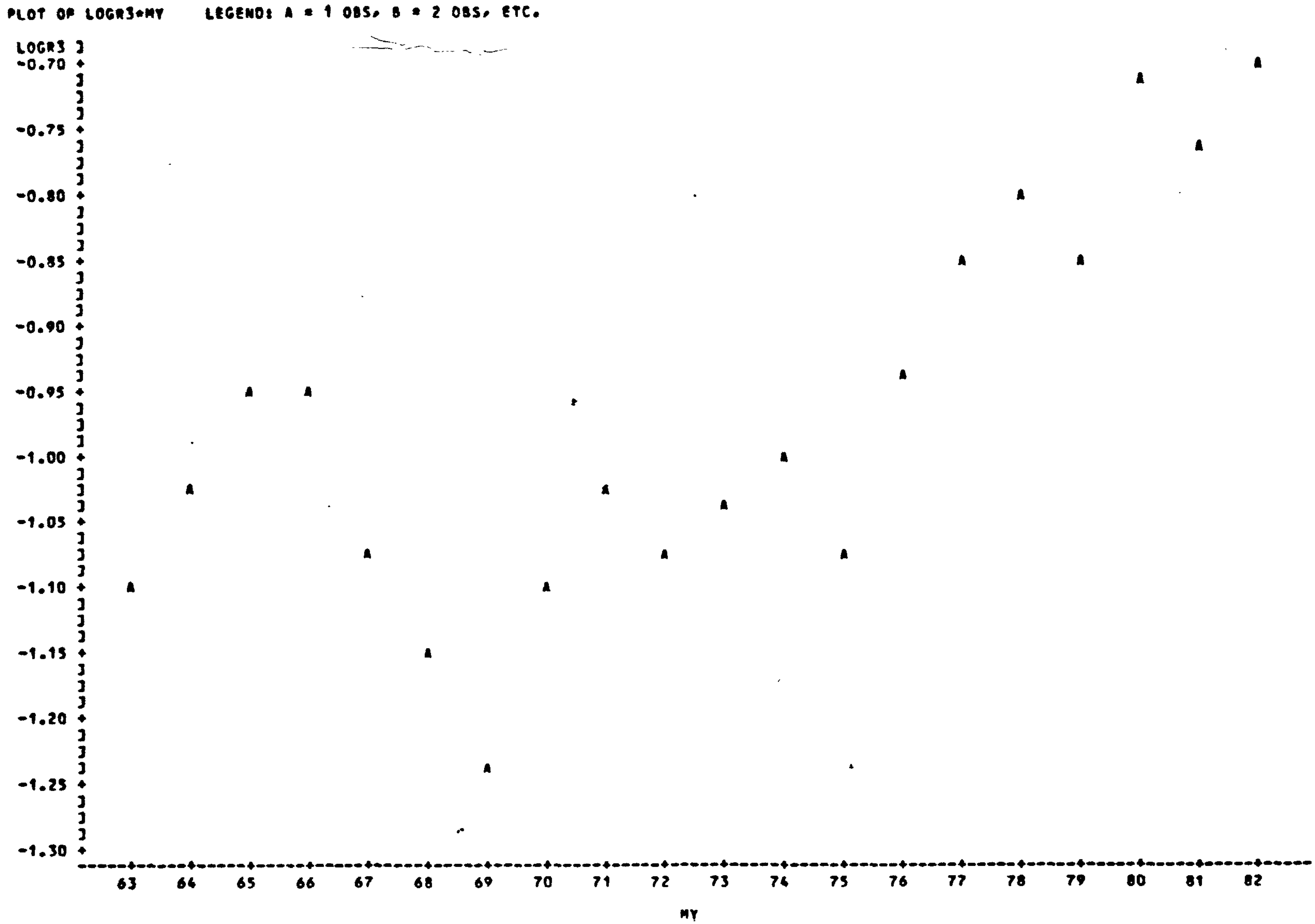


FIGURE 5-2B: LOG ODDS RATIO OF ROLLOVERS TO FRONTAL FIXED OBJECT IMPACTS, BY MODEL YEAR (Calendar year correction excluding vehicle age term)



5.4 Rollover propensity by market class

The trend in rollover propensity is more easily understood if the passenger car fleet is split into market classes and the various classes separately analyzed. That will provide a combined cross sectional and time series analysis. Also, since individual market classes tend to contain a set of cars, drivers and driving environments that change relatively little from year to year, the effect of changes in vehicle design should be more readily apparent.

Seven market classes are used throughout the analysis:

1. Volkswagens
2. All imports other than Volkswagens, including captive imports
3. Domestic subcompacts: Vega, Monza, Chevette, Cavalier, Pinto, Escort, Omni, Gremlin/Spirit and their corporate sisters
4. Domestic compacts: Nova, Citation, Falcon, Maverick, Fairmont, Dart, Aspen, Chrysler K-cars, Rambler/American, Hornet/Concord and their corporate sisters
5. Domestic intermediates: Malibu, Monte Carlo, Celebrity, Fairlane, Torino, Granada, LTD II, Coronet, Charger, Mirada, Diplomat, Rebel/Classic and their corporate sisters
6. Large domestic cars: Caprice/Impala, 98, DeVille, Fleetwood, Riviera, Galaxie/LTD, Lincoln, Lincoln Mark, Polara/Monaco, Gran Fury, Newport, New Yorker, St. Regis, Imperial, Ambassador and their corporate sisters
7. Sporty domestic cars: Corvette, Camaro, Firebird, Mustang, domestic Mercury Capri, EXP, Challenger, Barracuda, AMX, Javelin

Cougars and Thunderbirds are omitted from the analysis because they are not readily classifiable. Corvairs are also omitted because their design is quite different from other domestic compacts.

The data were grouped by market class and model year. Figure 5-3A is a graph of LOGR2, while Figure 5-3B shows LOGR3. In each case, the numbers on the graph represent the market class.

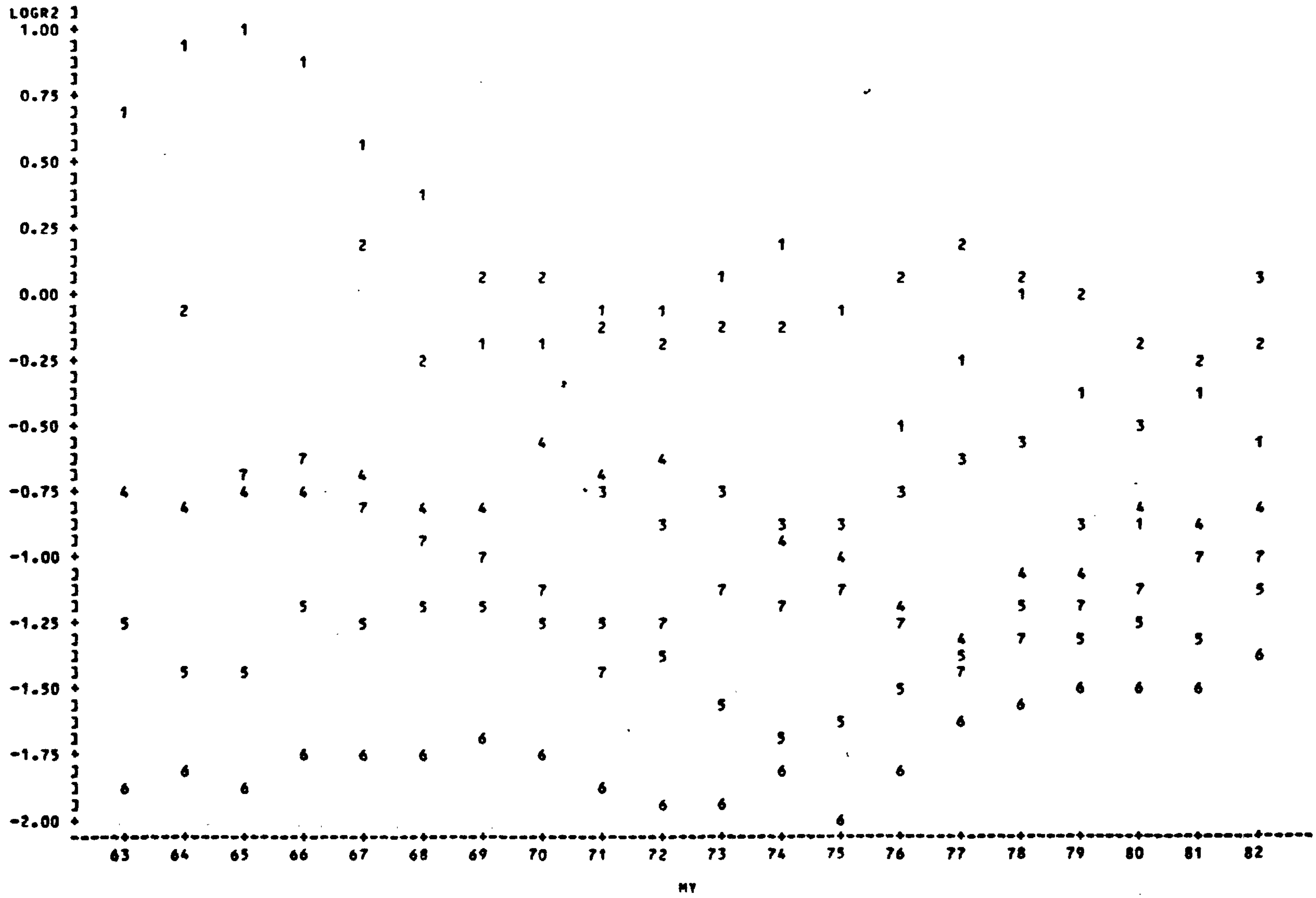
The most obvious fact is that the differences between market classes far exceed the year to year changes within market classes. Imported cars - classes 1 and 2 - have about as many rollovers as fixed object impacts (LOGR2 and LOGR3 are close to zero), whereas large domestic cars - class 6 - have about 15 rollovers per 100 fixed object impacts. That is nearly a 7 to 1 difference in rollover propensity.

Another conspicuous feature of Figures 5-3A and 5-3B, as indicated by the "1's" on the graphs, is the exceptionally high rollover rate of Volkswagens (primarily Beetles) in the mid 1960's. They have as many as 210-270 rollovers per 100 fixed object impacts, which is over double the rate of other small cars. But the situation improves dramatically in 1967-69. During 1969-74 the rollover rate for Beetles is about the same as for other imported cars and only slightly higher than the rate for the front engine Volkswagens (model year 1975 and beyond). These accident statistics confirm earlier studies [11], [32], [34] indicating that Volkswagens were highly rollover prone in the 1960's (see Section 2.2). It remains to find out whether the high rate is what would be expected in view of the Beetle's light, narrow build or if additional vehicle factors are involved.

Imported cars other than Volkswagens (class 2) have a nearly

FIGURE 5-3A: ROLLOVER PROPENSITY BY MODEL YEAR AND MARKET CLASS
(Calendar year correction <u>including</u> vehicle age term)

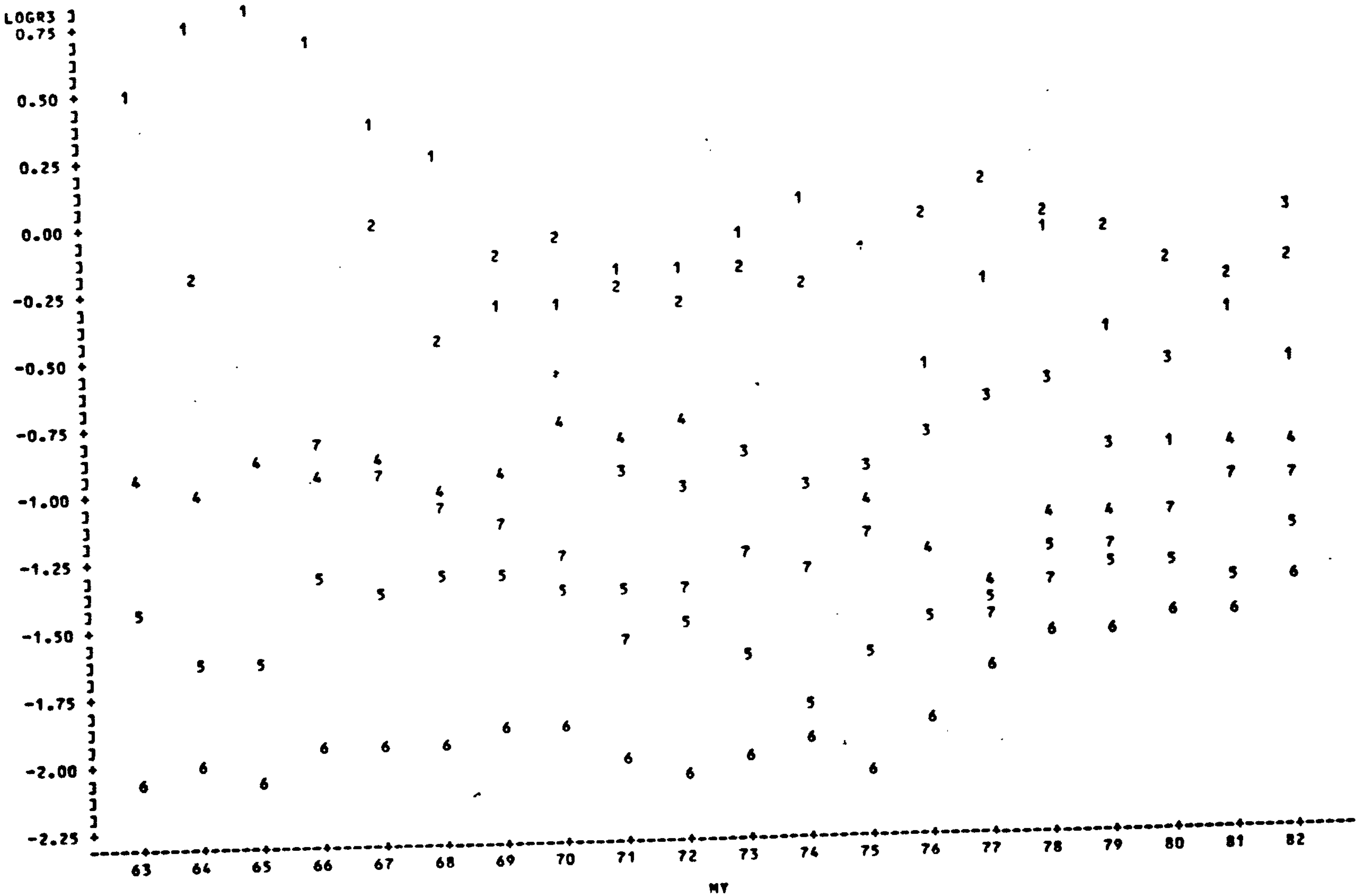
PLOT OF LOGR2*MY   SYMBOL IS VALUE OF CARGP



NOTE: 3 OBS HIDDEN

FIGURE 5-3B: ROLLOVER PROPENSITY BY MODEL YEAR AND MARKET CLASS
(Calendar year correction excluding vehicle age term)

PLOT OF LOGR3*MY SYMBOL IS VALUE OF CARGP



NOTE: 7 OBS HIDDEN

uniform, high rollover rate, although there appears to be a modest but steady improvement after 1975. That trend is consistent with the tendency of foreign manufacturers, especially the Japanese, to build wider cars. For example, the Honda Civic and Toyota Corolla became 3 inches wider during 1975-82 and the basic Nissan sedan, 5 inches.

Domestic subcompacts (class 3), on the other hand, started out as well as domestic compacts in the early 1970's but have gradually deteriorated to the level of Volkswagens and other imports. Again, that is consistent with design trends. For example, the Vega and Pinto, introduced in 1971, were 4 inches wider than the Chevette, introduced in 1976. Another possible explanation is that the early subcompacts were used primarily in urban low speed environments, where rollover rates are low, but later ones had more extensive rural usage.

The patterns for domestic compacts, intermediates and large cars (classes 4, 5 and 6) are almost parallel, with each successively large group significantly less prone to rollover than the preceding one. Rollover rates are nearly uniform, but they dip in the early to mid 1970's when the models were substantially "upsized" (see [47], pp. 127 and 301-319). The rates clearly rise in the later 1970's, as downsizing began. Moreover, the beginning of the rising trend coincides with the start of downsizing: the intermediates begin to rise in 1975, coincident with the introduction of Ford Granada; the large cars, in 1977, when GM downsized; and the compacts, not until 1980-81, when GM introduced the downsized front wheel drive models. Similarly, the pattern for sporty domestic cars (class 7) mirrors design trends. The early Mustang and Barracuda were about the weight and width of compact cars and had similar rollover proneness. The introduction of the wide, heavy Camaro and Challenger and a comparable upsizing of the Mustang coincides with a reduction to the level of domestic intermediates. Eventually, successive downsizings of Mustangs, followed by a downsizing of Camaros gradually brought the rate back to the level of compact cars.

The analysis of rollover proneness by market class helps explain the overall trend for passenger cars (Figures 5-2A and 5-2B). The sharp rise in 1963-65 coincided with the increasing popularity of the Volkswagen Beetle. Although it never accounted for more than 5 percent of car sales, it had enough rollovers to pull the fleet average visibly upwards. The large dip in 1967-69 coincided with the great improvement of the Beetle, plus increases in the size and weight of all cars. The modest deterioration during 1970-76 coincided with the increasing market shares for imports and small domestic cars, although the increases are tempered by the fact that cars were still growing within market classes. From 1977 onwards, the deterioration is more rapid as the shift to imports and small cars was compounded by downsizing within most of the market classes.

5.5 A model which adjusts for vehicle size and weight

So far, the time series and cross sectional data shows trends in rollover propensity which, in many cases, coincide with changes in vehicle size and weight. The next task is to perform a statistical analysis of rollover proneness by car size and weight and to use the results to adjust the rollover rates by model year for year to year changes in car size and weight.

The first step is a logistic regression of rollover propensity by track width, curb weight, wheelbase, car height, and car age - using pooled data. The regression somewhat resembles the one performed in Section 5.2 to compute the calendar year corrections, but the purpose is different. There, the vehicle size parameters were auxiliary variables and the calendar year coefficients were of primary interest. Here, the data are adjusted by the calendar year correction factors before they are entered in the regression and the primary objective is to calibrate the coefficients for the vehicle size variables.

All model years from 1963 to 1982 are used. The only data points that are discarded are the Volkswagens from 1968 and earlier. They are light, narrow cars, yet they are suspected of having rollover rates even beyond what would be expected for their size and weight. Their inclusion in the regression could cause the model to overestimate the coefficients for the size and weight variables. Volkswagens from 1969 onwards are included.

The reported rollover counts are adjusted by the calendar year correction factors as explained in Section 5.2, with separate analyses for the LOGR2 and LOGR3 correction factors. The corrected data are pooled across make/model, model year and calendar year, but grouped according to class intervals of track width (45-47, ... , 64-66 inches), curb weight

(1600-2399, ... , 4800-5599 pounds), wheelbase (70-87, ... , 128-135 inches), car height (46-47, ... , 58-59 inches) and vehicle age (0-2, 3-5, 6-8, 9-12 years). The dependent variables are LOGR2 and LOGR3, respectively, the corrected log odds ratios of rollovers to fixed object impacts. The independent variables are track width, curb weight, wheelbase, car height and car age (all continuous; the values used are the midpoints of the class intervals). There are 279 data points. The data points are weighted according to the number of actual, observed rollover cases in that group.

In the initial regressions, car height did not have a significant effect on either dependent variable. This does not necessarily imply that height is unimportant as a rollover propensity factor, merely that its inclusion in the regression did not appreciably improve R squared. As a result, it became possible to eliminate the height variable from the models. The accident cases were regrouped by the remaining variables, track width, curb weight, wheelbase and car age, condensing them to 133 regression data points. All of these variables had a significant effect on LOGR3. The regression coefficients for the model with <u>dependent variable LOGR3</u> are:

INTERCEPT	5.712	TRACK WIDTH	- .0911
CURB WEIGHT	- .000211	WHEELBASE	- .007
VEHICLE AGE	- .0258		

R squared is .96, a remarkable correlation. Essentially, the model says that rollover propensity decreases as cars get wider, heavier and longer. Track width, however, has by far the highest correlation. For a typical car with a track width of 55 inches, curb weight of 3000 pounds and wheelbase of 105 inches, a 1 percent increase in track width is associated with a .0911(.55) = 5 percent decrease in rollover propensity. A 1 percent increase in curb weight is associated with a .000211(30) = 0.6 percent decrease in rollover propensity. A 1 percent increase in wheelbase is associated with a .007(1.05) = 0.7 percent decrease in rollover propensity.

Wheelbase did not have a significant effect on LOGR2. As a result, it became possible to eliminate the wheelbase variable from the LOGR2 model. The accident cases were again regrouped by the remaining variables, track width, curb weight and car age, condensing them to 61 regression data points. All of these variables had a significant effect on LOGR2. The regression coefficients for the model with dependent variable LOGR2 are:

INTERCEPT	5.561	TRACK WIDTH	- .0962
CURB WEIGHT	- .000259	VEHICLE AGE	- .0317

R squared is .97, an even higher correlation. Note that the coefficients differ only a little from those of the preceding model.

It is interesting to compare these regression coefficients with results in other studies. Since the c.g. height of passenger cars is relatively constant [35], track width is highly correlated with the stability factor (half of track width/c.g. height), which has been shown to have high correlation with rollover propensity [37]. Wheelbase is an important factor in directional stability and net rollover propensity [90]. Curb weight may be well correlated with rollover propensity because it is highly correlated with track width and wheelbase and/or because it may have other relationships with directional stability and rollover stability [45], [60]. Moreover, track width, curb weight and wheelbase are all highly intercorrelated. It is conceivable that a multiple regression model could assign effects to one of these variables that should partly have been assigned to another, even to the point where the effect of the first variable loses statistical significance.

The next step is to use these regression coefficients to adjust the rollover rates by model year and market class. Figures 5-3A and 5-3B show the rollover rates prior to adjustment. It may be recalled that there were large differences between market classes that stayed fairly consistent from year to year. Large cars were always lowest in rollovers; small cars highest. There were also noticeable year to year trends.

For each data point (market class - model year combination) the average values of track width, curb weight, wheelbase, and vehicle age at the time of the crash are computed in the Texas data set. Define

$$\text{PROPEN2} = \text{LOGR2} + .0962\ \text{TRACK WIDTH} + .000259\ \text{CURB WEIGHT} + .0317\ \text{VEHICLE AGE}$$

and

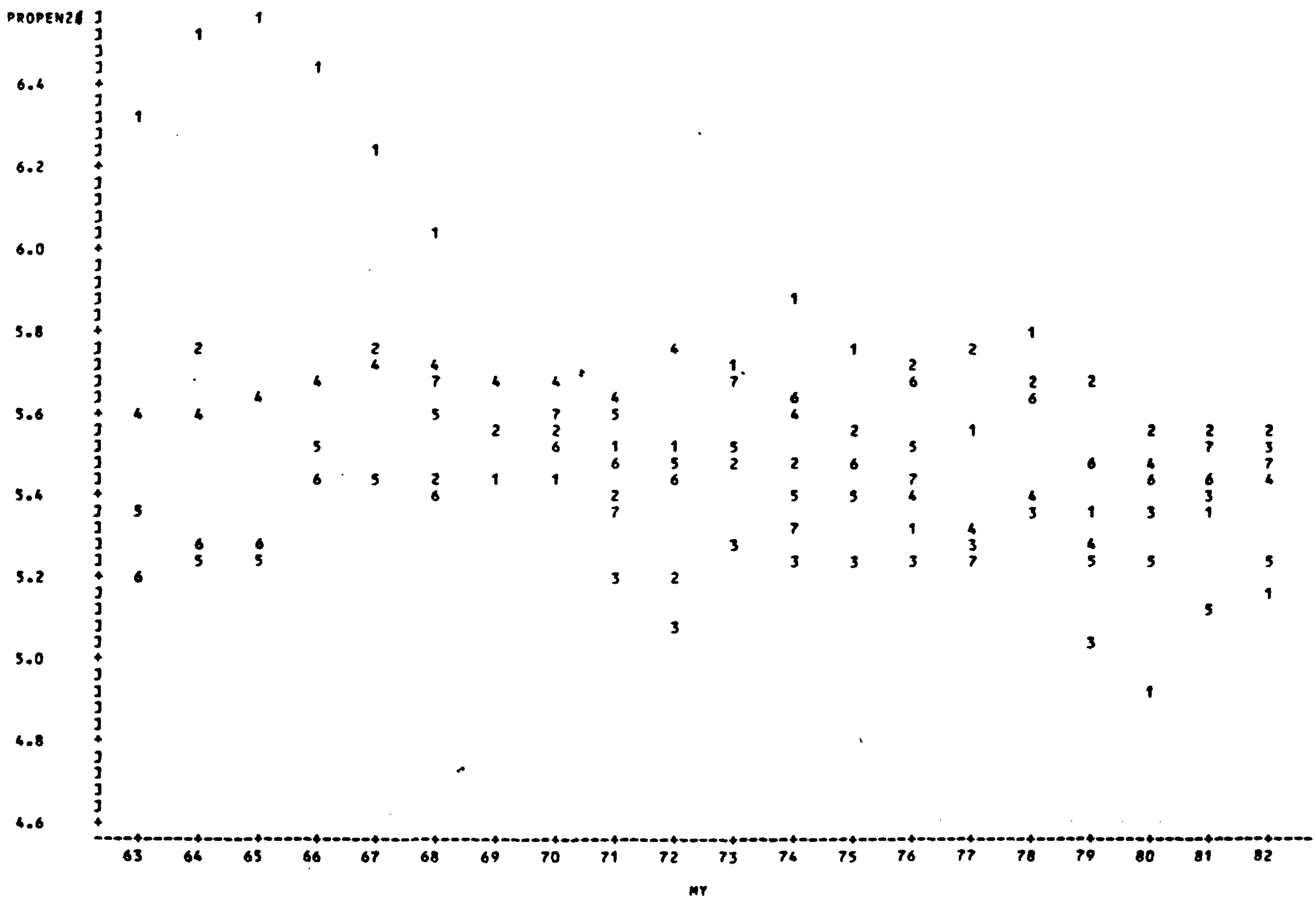
$$\text{PROPEN3} = \text{LOGR3} + .0911\ \text{TRACK WIDTH} + .000211\ \text{CURB WEIGHT} + .007\ \text{WHEELBASE} + .0258\ \text{VEHICLE AGE}$$

where LOGR2 and LOGR3 are the values graphed in Figures 5-3A and 5-3B, respectively.

Figures 5-4A and 5-4B display the adjusted rollover propensities PROPEN2 and PROPEN3. Figures 5-5A and 5-5B show the same data, but

FIGURE 5-4A: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR AND MARKET CLASS (Calendar year correction <u>including</u> vehicle age term)

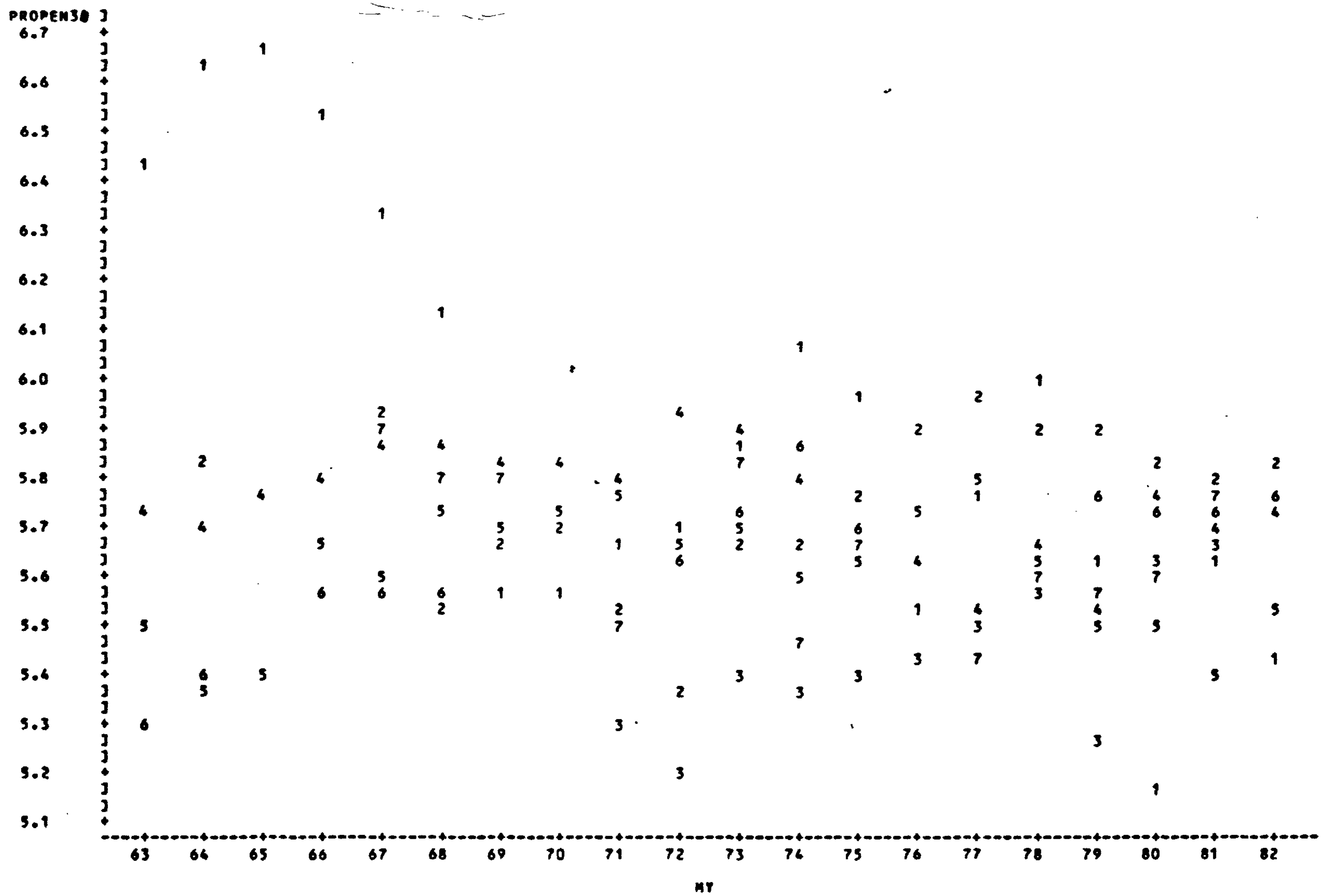
PLOT OF PROPENZ@*MY   SYMBOL IS VALUE OF CARGP



NOTE: 21 OBS HIDDEN

FIGURE 5-4B: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR AND MARKET CLASS (Calendar year correction excluding vehicle age term)

PLOT OF PROPEN3@*MY SYMBOL IS VALUE OF CARGP



NOTE: 15 OBS HIDDEN

FIGURE 5-5A: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR AND MARKET CLASS – Drawn to the Same Scale as the Unadjusted Data (Calendar year correction including vehicle age term)

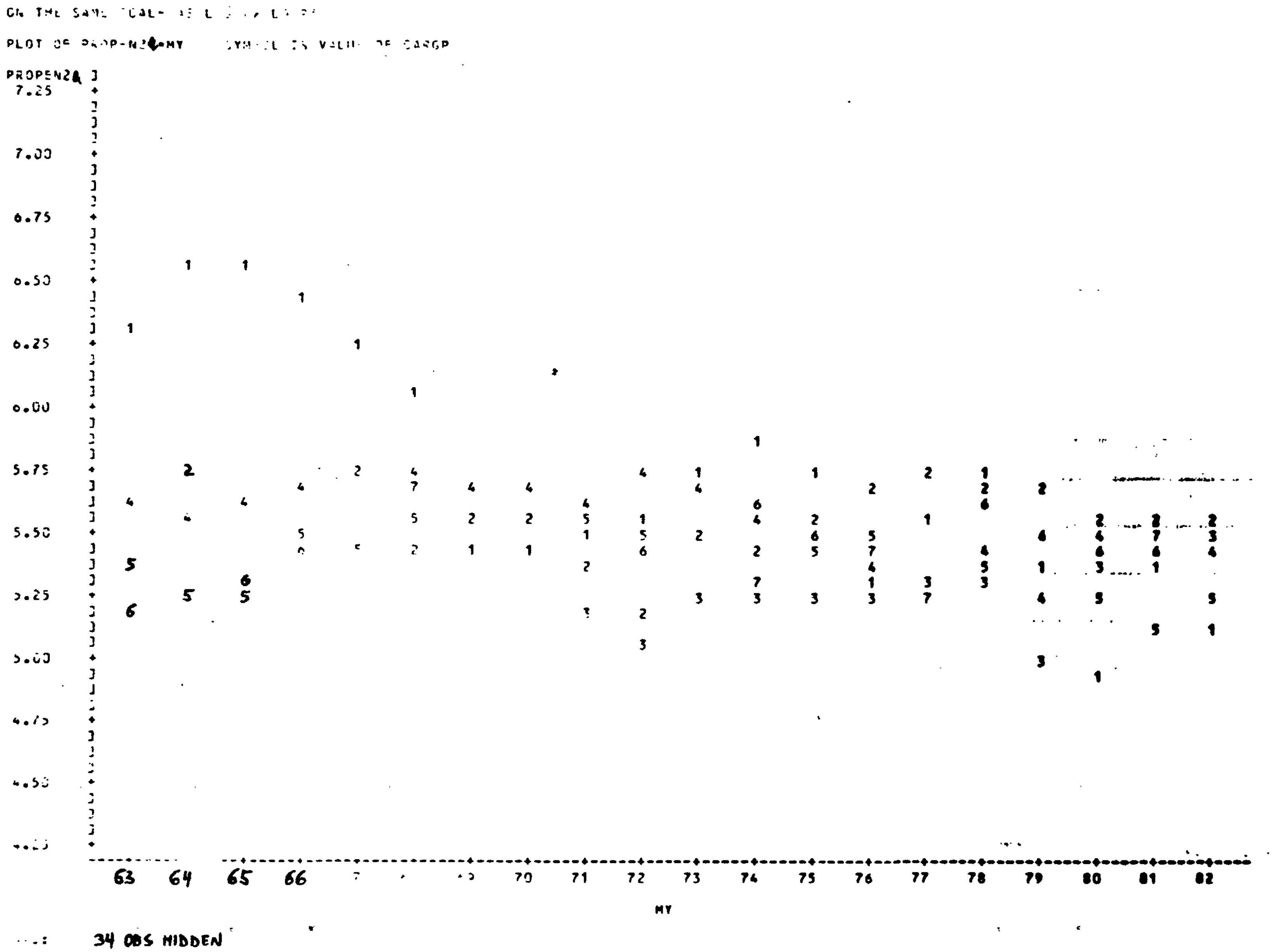
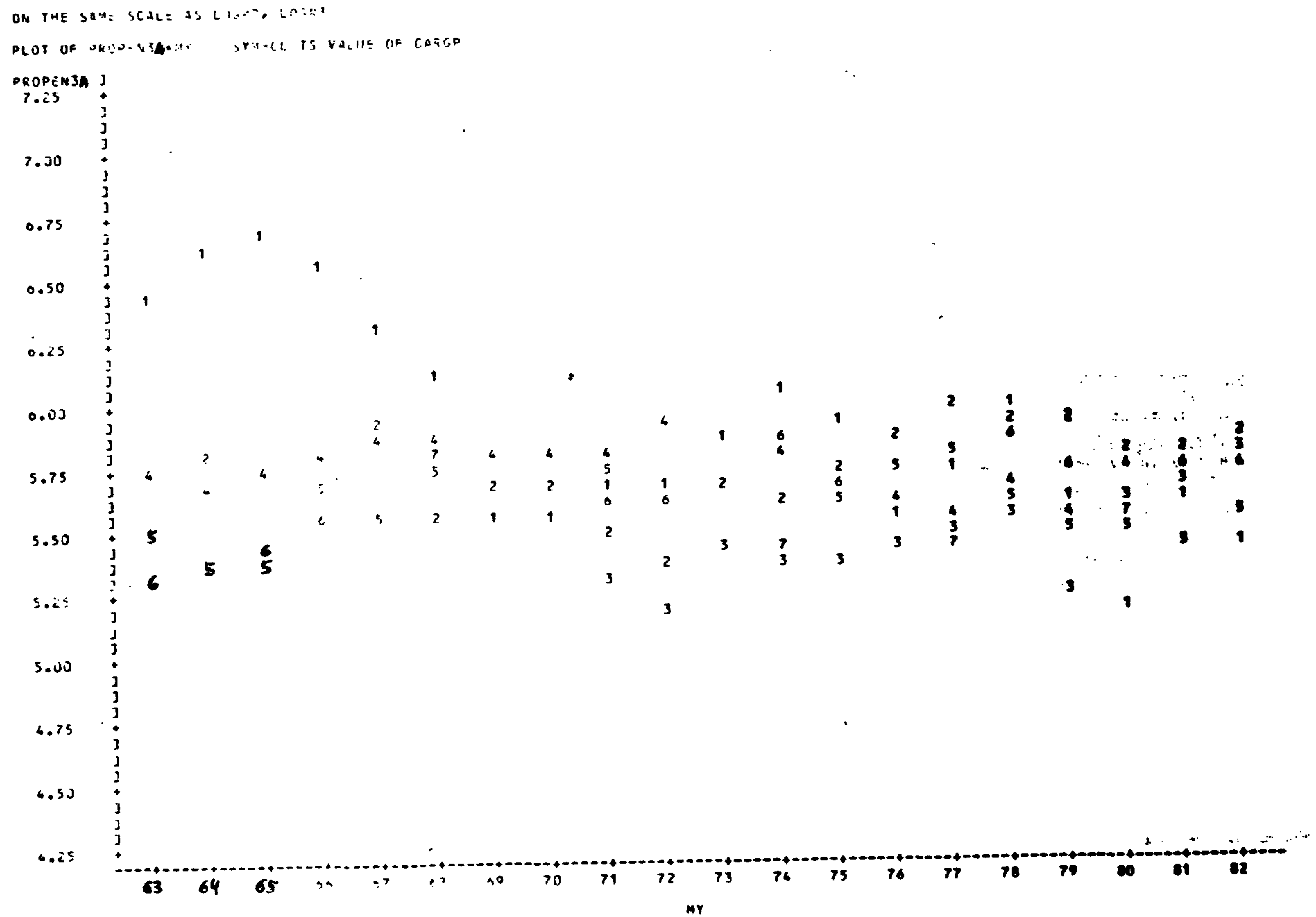


FIGURE 5-5B: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR AND MARKET CLASS – Drawn to the Same Scale as the Unadjusted Data (Calendar year correction <u>excluding</u> vehicle age term)



NOTE: 32 OBS HIDDEN

drawn to the scale used for the unadjusted rates (Figures 5-3A and 5-3B). The numbers on the graphs represent the car market classes defined in Section 5.4.

Several phenomena are immediately apparent from Figures 5-4 and 5-5, especially in comparison with Figure 5-3. The values of PROPEN2 and PROPEN3 are in a much narrower band than LOGR2 and LOGR3; that is most apparent from Figure 5-5, which uses the same scale as Figure 5-3. The bands for PROPEN2 and 3 are about one fifth as wide as for LOGR2 and 3. The one exception is the Volkswagen Beetle prior to 1969, which is now seen to have significantly higher rollover propensity than would be expected on size and weight considerations alone. All the other market classes, including Volkswagens from 1969 onwards, are pretty well scrambled in Figures 5-4 and 5-5. For example, large domestic cars (class 6), which always had the lowest rollover rates in Figure 5-3, are generally in the middle of the pack after adjusting for size and weight. Besides the early Volkswagens, the only vehicles departing even slightly from the average are the 1971-76 domestic subcompacts, on the low side and 1976-82 imports other than VW, on the high side. The slightly lower rate for the early domestic subcompacts may reflect their limited use on rural roads; the slightly higher rate for imported cars might reflect an overrepresentation of younger drivers and/or unknown vehicle factors. Neither group stands out visibly from the pack.

Finally it is important to note that, aside from the Volkswagen phenomenon, the data points in Figures 5-4 and 5-5 show little drift upwards or downwards, as a function of model year. Major long term trends such as downsizing appear to be neutralized by the adjustment process.

The last step of the modeling process is to aggregate the data points in Figures 5-4A and 5-4B across market classes and obtain an estimate of the average intrinsic rollover propensity by model year, after adjusting for car size and weight. Figure 5-6A displays the average PROPEN2 for all passenger cars, by model year, while Figure 5-6B shows PROPEN3. Both figures show essentially the same pattern. There is a sharp increase form 1963 to 1966, corresponding to the growing popularity of the Volkswagen Beetle, whose rollover rate is high enough to pull up the average for all passenger cars. Modifications of the Volkswagen during 1966-69 lowered its rollover propensity to the normal level for a car of its weight and size; as a result, the average rollover propensity for the entire vehicle fleet dropped back to the 1963 level. From model year 1969 onwards, rollover propensity remains almost unchanged, after taking size and weight into account. The fleetwide averages in Figures 5-6A and 5-6B vary within a bandwidth of just 0.17 after model year 1969, with no obvious trend. Such variations are easily within the "noise" level of the data.

5.6 Rollover propensity indices

The Texas data can be used to generate rollover propensity indices for the entire passenger car fleet, by model year, analogous to the frontal crashworthiness indices defined in NHTSA's evaluation of occupant protection in interior impact [47]. In the preceding analyses,

FIGURE 5-6A: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR
(Calendar year correction <u>including</u> vehicle age term)

PLOT OF PROPEN2#*MY   LEGEND: A = 1 OBS, B = 2 OBS, ETC.

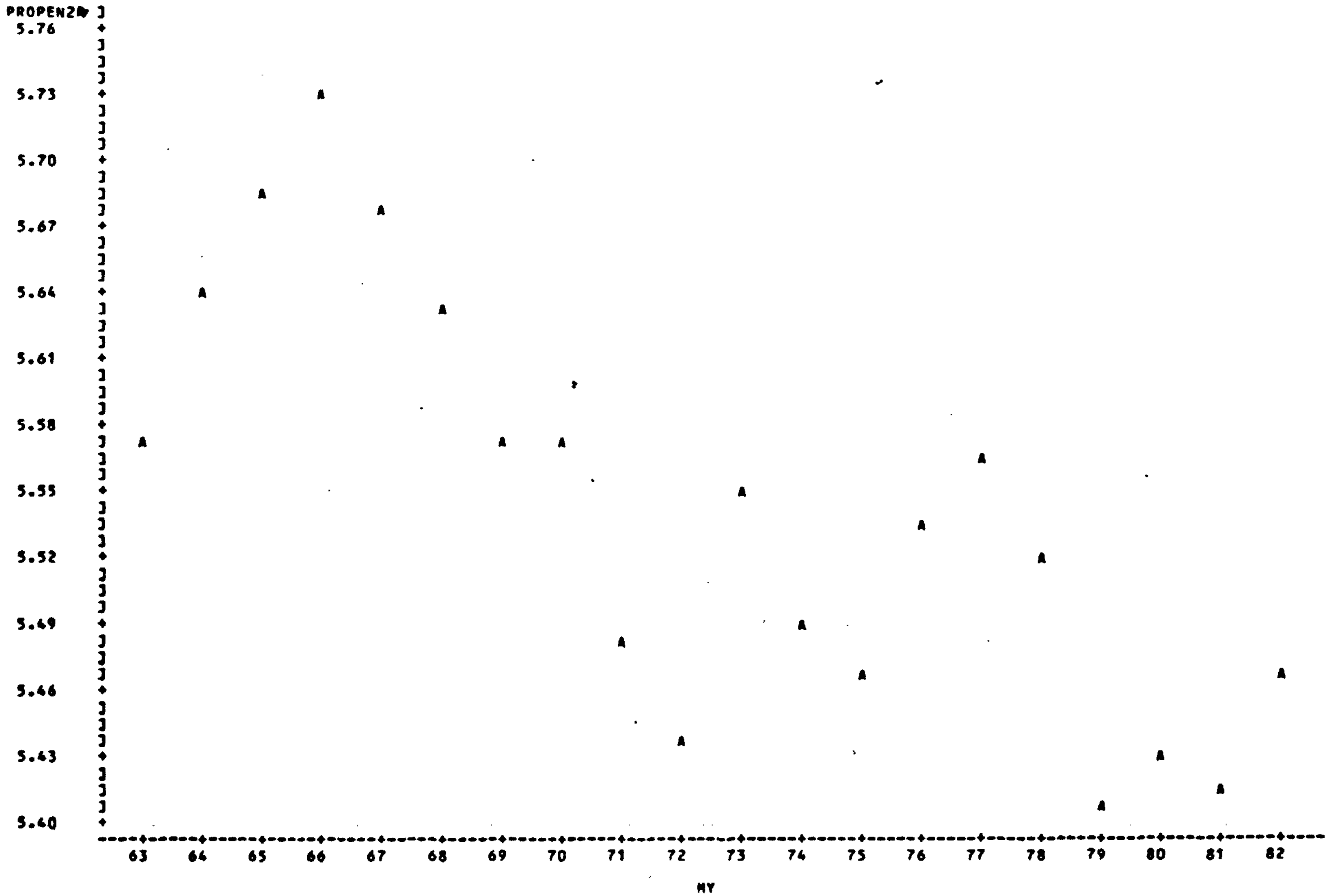
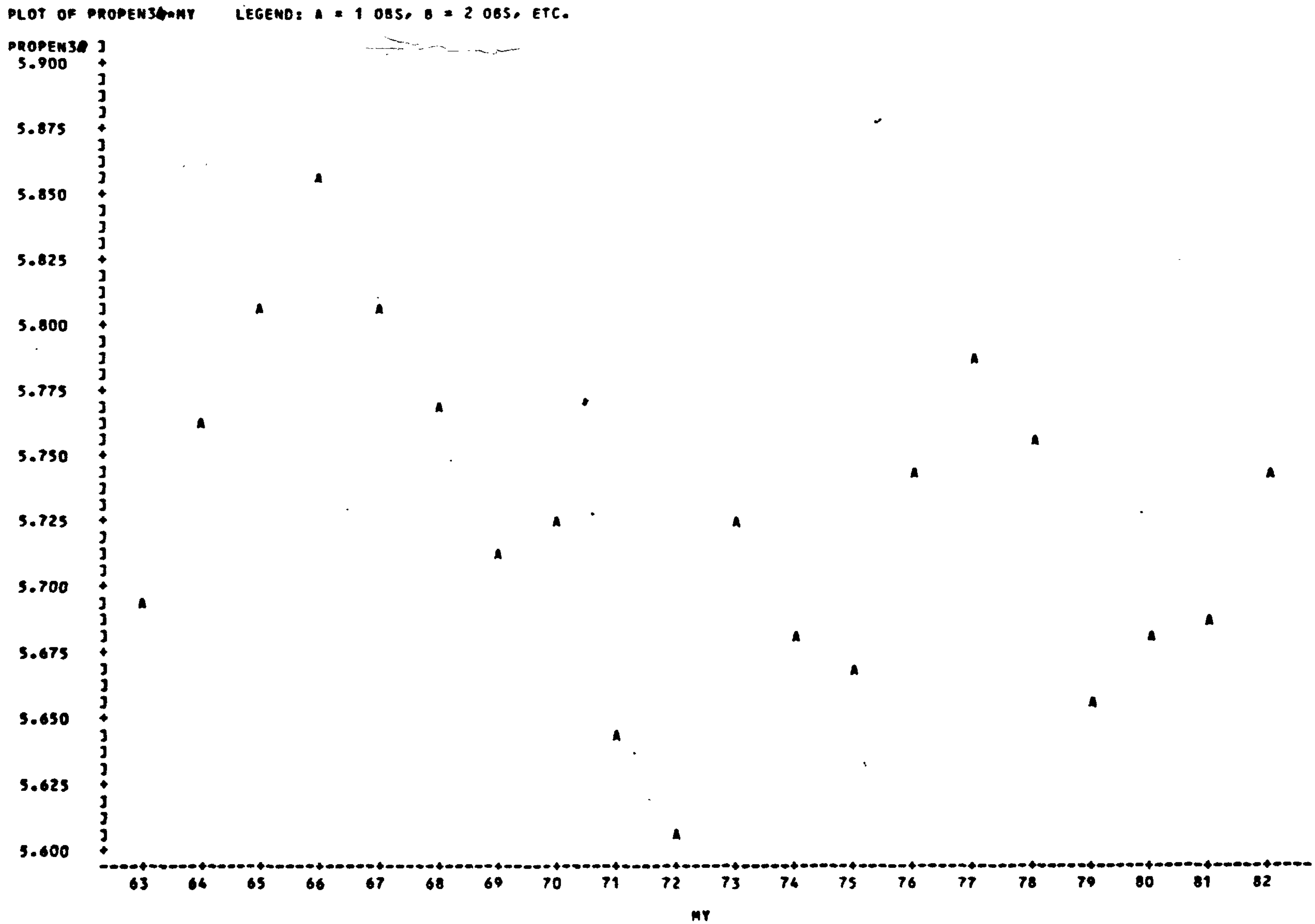


FIGURE 5-6B: ROLLOVER PROPENSITY, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR
(Calendar year correction <u>excluding</u> vehicle age term)



LOGR2, LOGR3, PROPEN2 and PROPEN3 represented the logarithm of the odds ratio of rollovers to fixed object impacts, with or without adjustment for car size and weights. Let LOGR2(75-80) be the average of the values of LOGR2 for model years 1975 through 1980. For any model year MY, the index is set equal to 100 exp[LOGR2(MY)]/exp[LOGR2(75-80)]. In other words, the index averages close to 100 for the baseline model years 1975-80 and is higher than 100 in model years where LOGR2 is higher than the average for the baseline years. The procedure is similar for LOGR3, PROPEN2 and PROPEN3. If the index is 100 in one model year and 90 in the next, it means that rollover propensity decreased by 10 percent (with or without adjustment for car size and weight, depending on which variable is used to calculate the index).

The values of the indices are:

Model Year	Index Based On			
	LOGR2	LOGR3	PROPEN2	PROPEN3
1963	90	79	109	97
1964	97	86	117	105
1965	104	92	121	109
1966	105	93	127	115
1967	92	82	121	110
1968	84	76	115	105
1969	77	70	108	100
1970	88	80	109	101
1971	93	86	99	93
1972	89	82	95	90
1973	89	85	106	101
1974	90	88	100	96
1975	83	82	98	95
1976	94	93	105	103
1977	103	103	108	107
1978	107	108	103	104
1979	100	102	92	94
1980	114	117	94	97
1981	108	112	93	97
1982	114	119	98	103

Figure 5-7A graphs the indices based on LOGR2 and PROPEN2. The unadjusted index based on LOGR2 is shown as "R" on the figure and the adjusted index based on PROPEN2 is shown as "A." The unadjusted index takes an initial rise and dip in 1963-69 at the time of the Volkswagen phenomenon and rises steadily thereafter as the market shifted to smaller cars and cars were downsized within market classes. The adjusted index starts just above 100, rises as high as 127 at the time of the Volkswagen phenomenon, drops back to 99 by 1972 and remains close to 100 in all subsequent model years. Figure 5-7B graphs the indices based on LOGR3 and PROPEN3, revealing similar patterns, although the adjusted index only gets as high as 115 at the peak of the problem with the Volkswagens. In other words, the intrinsic rollover propensity of domestic cars during 1963-82 and imported cars during 1969-82 was nearly invariant after taking size and weight changes into account.

FIGURE 5-7A: ADJUSTED (Plain Line) and UNADJUSTED (Hatched Line) ROLLOVER PROPENSITY INDICES (Calendar year correction <u>including</u> vehicle age term)

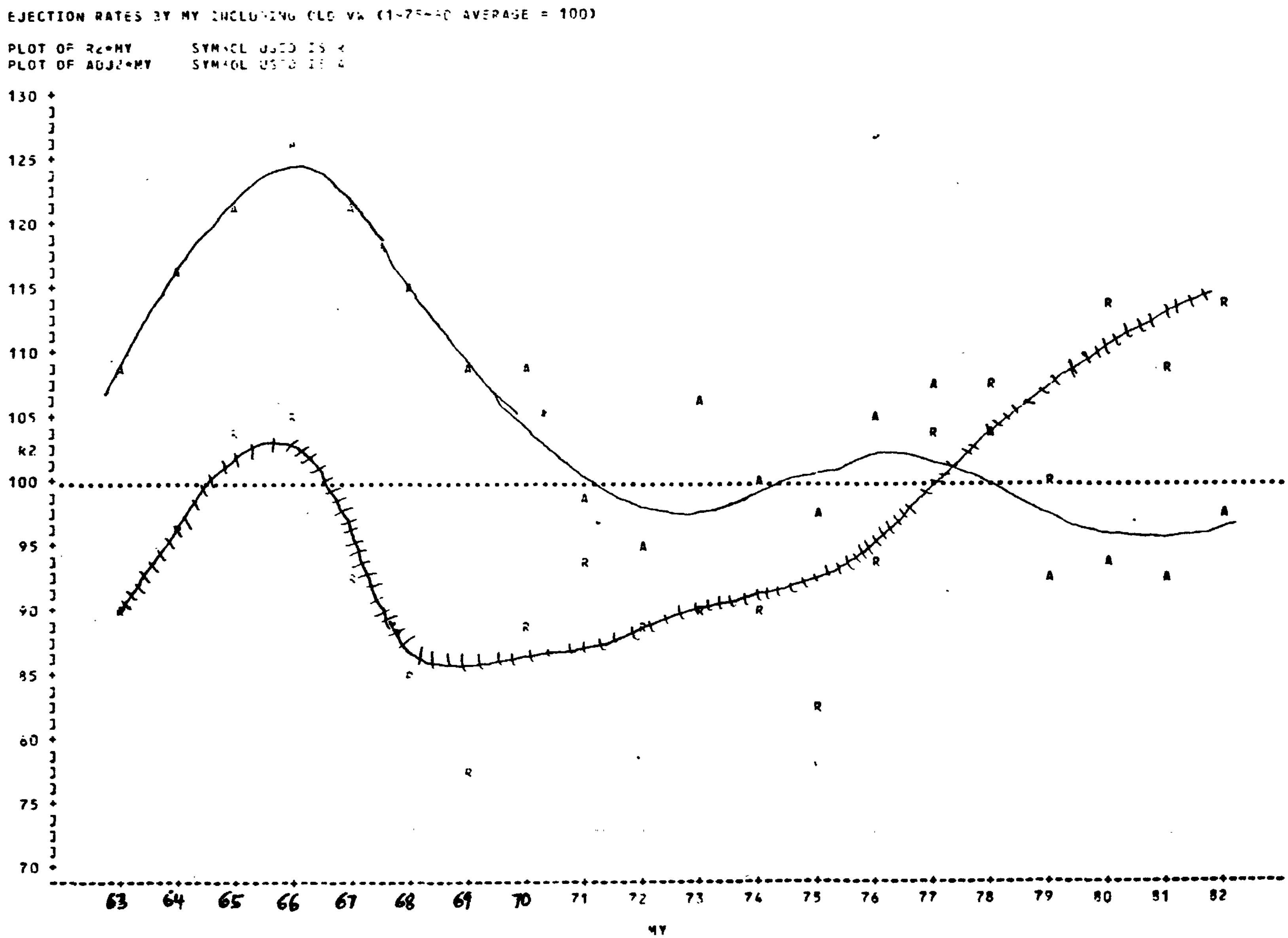
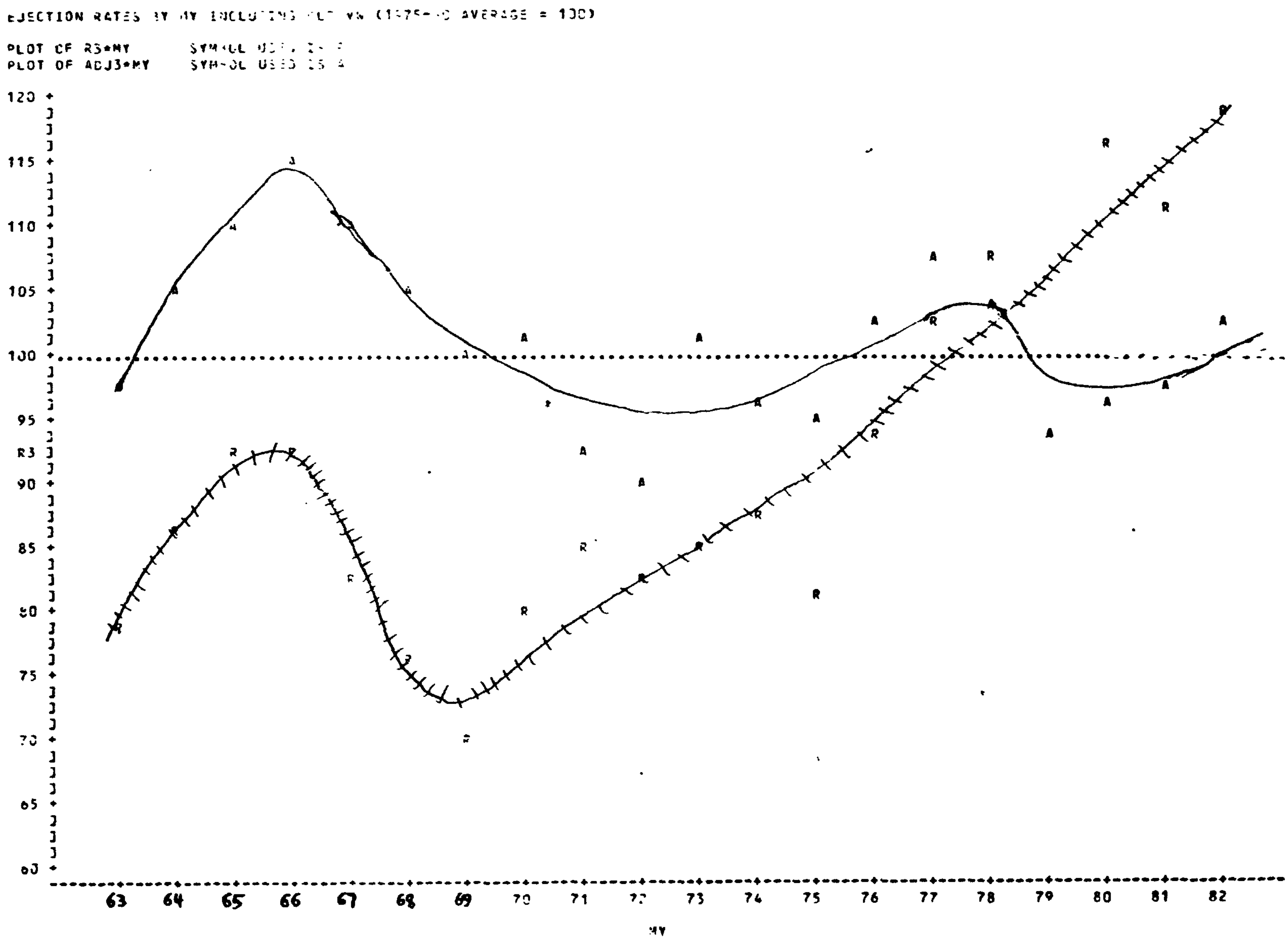


FIGURE 5-7B: ADJUSTED (Plain Line) and UNADJUSTED (Hatched Line) ROLLOVER PROPENSITY INDICES (Calendar year correction excluding vehicle age term)



CHAPTER 6

ROLLOVER FATALITY RISK BY MODEL YEAR: ANALYSES OF FARS DATA

Fatal Accident Reporting System data for calendar years 1975-86 were tabulated by model year to see if the rollover fatality risk of passenger car occupants changed significantly between model years 1963 and 1982. Initial analyses suggest that rollover fatality risk varied greatly during those years; for example, it was about 35 percent higher for 1980-82 cars than 1971-73 cars. More detailed analyses show that much of the variation coincided with changes in the size and weight of cars. Smaller cars have more rollovers and, as a result, more fatalities. The fatality rates are adjusted for vehicle size parameters in order to isolate the effect of crashworthiness improvements.

The door lock, latch and hinge improvements in domestic cars of the mid to late 1960's reduced ejection fatalities in rollovers by approximately 10 percent. Another factor influencing ejection fatality risk is the number of doors. Four door cars are intrinsically better than two door cars when it comes to keeping the occupant inside the car: the ejection fatality rates in rollovers are 25 percent lower in 4 door than in 2 door cars even after controlling for car size and weight. Thus, the shift from 4 door to 2 door cars during the 1960's and early 1970's was detrimental to safety, while the resurgent popularity of 4 door cars since the late 1970's is saving lives.

For several years before and after the 1974 effective date of

Standard 216, the manufacturers gradually shifted their production from genuine to pillared hardtops or, as a temporary measure, strengthened existing hardtops. Since pre-Standard 216 hardtops had a 14 percent higher risk of nonejection fatality in rollover crashes than pre-Standard 216 pillared cars, the shift in car design significantly reduced fatality risk. Standard 216 had little effect, if any, on coupes and sedans.

The findings of this chapter should be viewed in combination with the next chapter, in which rollover fatality risk is analyzed based on FARS and Texas data together.

6.1 Analysis objectives and approach

The objective of the analysis, as stated in Section 1.4, is to compare the intrinsic rollover fatality risk of cars of different model years: to track the trend from model year 1963 to 1982. As a first step, measures of "intrinsic" rollover fatality risk should filter out influences other than the design of the vehicle: driver, roadway and data reporting factors. Similar to Chapter 5, the fatality risk is the log of the odds ratio of fatalities in rollovers to fatalities in frontal impacts with fixed objects, as reported in FARS (see Section 5.1). The frontal fatalities are a surrogate measure of exposure. Thus, fatality risk is the number of fatalities per unit of exposure, not the number of fatalities per 100 rollover crashes. The overall trend line of fatality risk by model year will not show, initially, whether changes in fatality risk are due to changes in rollover frequency (crash avoidance capability) or likelihood of death given a rollover (crashworthiness).

Subsequently, more detailed analyses will isolate the crashworthiness trends from the trends in rollover frequency. As in Chapter 5, that will be accomplished by adjusting the fatality rates for vehicle track width, weight and other factors correlated with rollover propensity. Finally, the effects of individual crashworthiness improvements will be isolated. Ejection and nonejection fatalities will be analyzed separately: the former, to study the effect of door lock improvements; the latter, to study roof crush resistance.

In Chapter 5, the control group was frontal impacts with fixed objects; here it is <u>fatalities</u> in frontal impacts with fixed objects. One difference is that the fatal frontal impacts are not a perfect control group. It is known that frontal fatality risk decreased significantly during the late 1960's. NHTSA's evaluation of occupant protection in frontal interior impacts provides a year by year index of fatality risk in frontal crashes, which improved throughout model years 1967-73, but remained fairly constant from then on through 1984 [47], pp. 157-163. The numbers of frontal fatalities observed in pre-1973 cars will need to be divided by the risk index to obtain the number that "would have occurred" if they had been later cars. That will make frontal fatalities a consistent measure of exposure for the 1963-82 period. Unlike earlier analyses of rollover rates [33], [36], [37], [45], [90],the control group is limited to <u>frontal</u> fixed object impacts and excludes other nonrollover single vehicle crashes such as side impacts with fixed objects. That is because the year-by-year fatality risk indices have so far been computed only for the frontals - and without the risk indices, it is impossible to adjust the control group data.

6.2 Data preparation, key variables and calendar year correction

In the analyses of FARS data [16], [17], a "rollover fatality" is any passenger car occupant, including rear seat occupants, who was killed in a primary rollover crash. A "primary rollover" crash is one in which the first harmful event was an overturn (HARM_EV = 1) or the most harmful event was an overturn (M_HARM = 1) or the principal damage was to the top of the car (IMPACT2 = 13). In other words, "primary rollovers" can include crashes where the rollover was a subsequent event, but only if it was considered the most severe event. A "rollover ejection fatality" is a rollover fatality who was known to have been ejected (EJECTION = 1 or 2). All other rollover fatalities are included among "rollover nonejection fatalities." In particular, persons with unknown ejection status (EJECTION = 9) are assumed not to have been ejected (in 1975 and 1976 FARS data, there are many unknowns and they were mostly not ejected, while in later years, unknowns are rare enough that it doesn't matter which way they are classified).

A "frontal impact with a fixed object" is a single vehicle crash in which a passenger car collides with a fixed object or a large nonfixed object such as a train, parked vehicle or animal; the primary damage to the car has to be frontal (IMPACT2 = 1, 11 or 12). Excluded are primary rollovers and collisions with pedestrians or pedalcyclists (M_HARM = 8 or 9; or M_HARM unknown but HARM_EV = 8 or 9). A "frontal fixed object fatality" is any occupant, including rear seat occupants, who was killed in a frontal impact with a fixed object.

"Passenger cars" include coupes, sedans, hardtops and station wagons (BODY_TYP = 2-9) but convertibles and automobile-based trucks are excluded. Occupants who were known to be restrained (MAN_REST = 1-8) were also excluded, so as to eliminate the effect of belt use trends from this study of rollover fatality risk. The 1975-86 FARS files contain records of approximately 30,000 rollover ejection fatalities, 20,000 rollover nonejection fatalities and 55,000 frontal fixed object fatalities.

Six key variables were derived from FARS or added from other sources. For each model year and make/model combination, the track width and the height of the cars are derived from Automotive News Almanacs [2]. Curb weights are also derived from the Almanacs, superseding the less reliable vehicle weights on FARS (see [47], p. 118 for discussion). Wheelbase information on FARS from model year 1966 onwards is identical to the data in the Almanacs. The average of WHLBS_LG and WHLBS_SH is used, after conversion to inches. For model year 1965 and earlier, wheelbase information is appended from the Almanacs. The preceding four variables - track width, curb weight, wheelbase and height - are identical to the ones used in Chapter 5. They are available on every FARS case with known make/model and are included because of their effect on the frequency of rollover. Appendix B lists the values by make/model and model year.

Two more variables are added because their suspected relation to the likelihood of fatality given a rollover. The number of doors is important because it influences the likelihood of ejection and, as a result, fatality risk, given a crash has occurred - see NHTSA's evaluation of seat back locks [52], pp. 137-146. Two door cars should have intrinsically higher rates of ejection because the doors are wider, having a greater tendency to bow at the time of impact and separate the latches from the frame. They also have a wider side window portal. From model year 1966 onwards, the FARS variable BODY_TYP has accurate information on the number of doors, consistent with the VIN. For model year 1965 and earlier, BODY_TYP is coded "2 door sedan" for all cars of many makes and models [52], p. 98. BODY_TYP is discarded for the pre-1966 cars and the number of doors is found by analyzing the VIN. It was also found that many pre-1966 cars were coded as unknown make/models (MODEL = 99) on FARS but their VINs were known. These VINs were decoded to obtain the make, model and number of doors.

The presence or absence of a B pillar may be important because pre-Standard 216 cars without B pillars (true hardtops) appear to have the lowest roof crush resistance, possibly resulting in higher fatality risk in the nonejection rollovers - see Section 1.3 and Chapter 3. The presence of a B pillar is determined by analyzing the VIN, using a program developed in NHTSA's evaluation of side door beams [49], p. 229. Great care must be used in the VIN analysis: as the manufacturers shifted from true to pillared hardtops during the 1970's, they often kept on calling them "hardtops." In other cases, true hardtops were called "sport sedans." The Multidisciplinary Accident Investigation editing manuals [65] provided the detailed information needed for the VIN analysis.

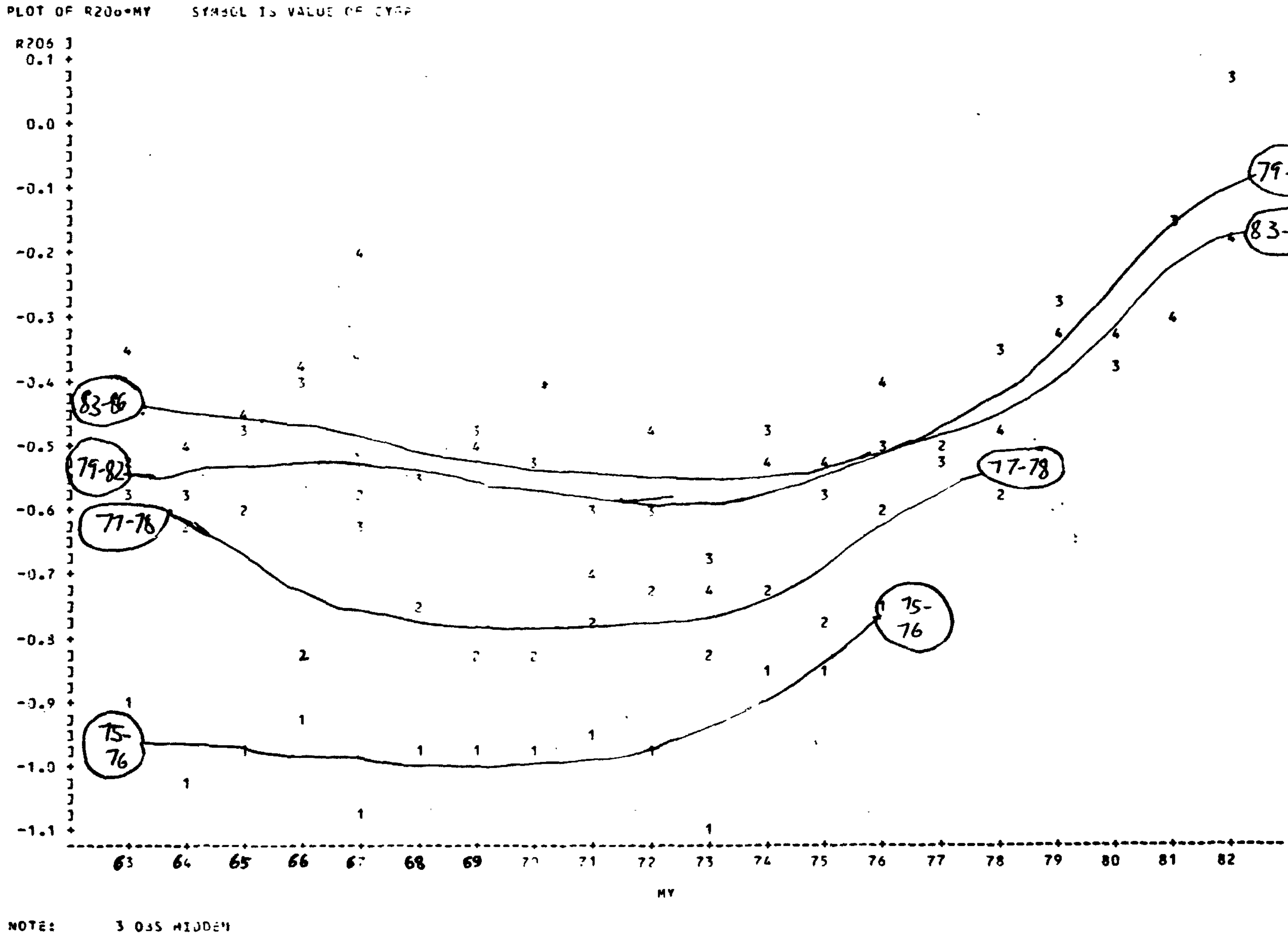
The first step in the analysis is to adjust the frontal fatalities of pre-1973 cars downwards to the levels they would have been if they had been as safe as current cars. As explained in the preceding section, that means dividing by the frontal fatality risk index developed in NHTSA's earlier evaluation of frontal impact protection [47], pp. 157-163. After averaging out some of the year to year variation, the values of the risk index are

122 for model years 1963-66
111 for model year 1967
105 for model years 1968-72
100 for model years 1973-82

In other words, 122 frontal fixed object fatalities in model year 1963 cars are about the same amount of "exposure" as 100 fatalities in model year 1982 cars. Thus, each frontal fixed object fatality in 1963 cars will be counted as only 1/1.22 fatalities in the remainder of the chapter.

Just as the Texas data in Chapter 5, the FARS data have some calendar year to year differences that need to be corrected. Moreover, the calendar year effects could be different for ejection and nonejection cases - as noted above, there were many missing data on ejection in 1975-76. The ejection and nonejection rollover fatalities and the frontal fixed object fatalities (corrected downwards in the pre-1974 cars) are tabulated by calendar year and model year. Figure 6-1 is a graph of the log odds ratio of rollover ejection fatalities to frontal fixed object fatalities, by model year, for various groups of calendar years. The calendar year effects are easily seen. In calendar years 1975-76, the rollover ejection fatality risk was consistently lower than in the subsequent years of FARS. The rate in calendar years 1977-78 was higher than in 1975-76, but generally lower than in 1979 and later years. The

FIGURE 6-1: REPORTED LOG ODDS RATIO OF ROLLOVER EJECTION FATALITIES TO FRONTAL FIXED OBJECT IMPACT FATALITIES, BY MODEL YEAR AND CALENDAR YEAR



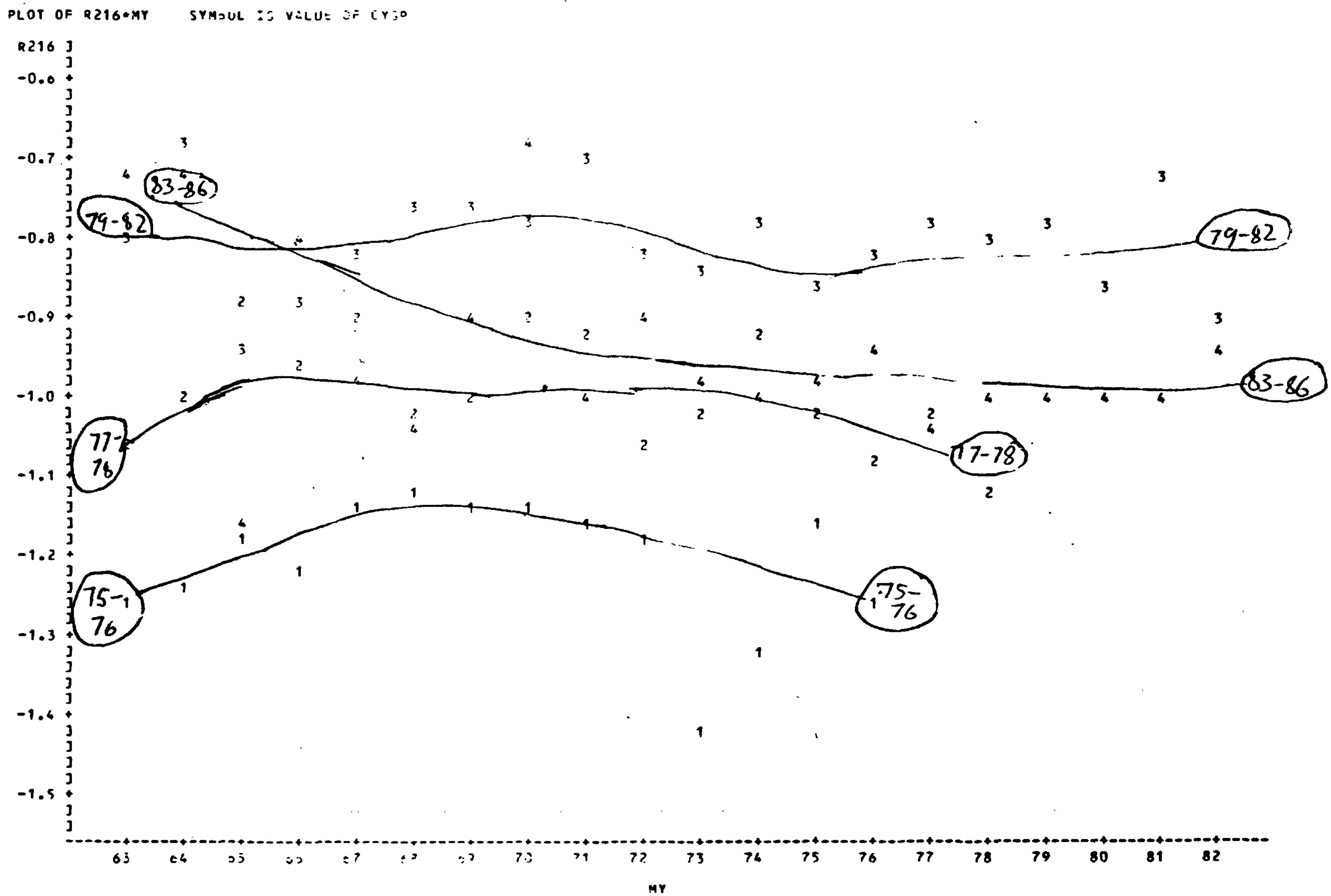
ejection rates during calendar years 1979-82 and 1983-86 were about the same.

Figure 6-2 is a graph of the log odds ratio of rollover nonejection fatalities to frontal fixed object fatalities, by model year, for various groups of calendar years. The calendar year effects are substantial, but not the same as for the ejection fatalities. The rate in calendar years 1975-76 is the lowest, as above, but here the rate for calendar years 1979-82 is consistently highest, while the rates for 1977-78 and 1983-86 are about equal and in the middle.

The calendar year effects are probably due mostly to rollover and/or ejection reporting differences. For example, the Most Harmful Event data element did not exist on FARS until 1979; a rollover that was a subsequent event and resulted primarily in side rather than top damage would not be included among the rollovers by the definition used here. In addition, some of the calendar effects may be due to real changes in the accident environment - e.g., lower speeds in the early years of the 55 mph speed limit may have reduced rollovers. Besides the calendar year effects, there may also be vehicle age effects at work (see Section 5.2)

The next step, as in Section 5.2, is to calibrate the calendar year and vehicle age effects in regressions which do not include the model year variable. Separate regressions are required for ejection and nonejection rollovers, since the calendar year effects are evidently not the same. Each regression should include appropriate <u>key variables</u>: track

FIGURE 6-2: REPORTED LOG ODDS RATIO OF ROLLOVER NONEJECTION FATALITIES TO FRONTAL FIXED OBJECT IMPACT FATALITIES, BY MODEL YEAR AND CALENDAR YEAR



width, curb weight, number of doors (for the ejectees) or presence of B pillars (for the nonejection fatalities).

For the regression of ejection fatality risk, the FARS data are tabulated by calendar year, model year, make/model code and number of doors (2 or 4). The regression is limited to cars of model years 1968-79. As can be seen in Figure 6-1, this is the middle range of model years where data from the various calendar years overlap. Also, all of these cars are post-Standard 206, meeting NHTSA's requirements for improved door locks and door retention components. That will help avoid biases in the analyses - e.g., attributing a high rollover rate to the earliest calendar years, because they are rich in pre-Standard 206 cars. The 1968 Volkswagen is also excluded from the regression, because it has a higher rollover rate than explained by the key variables, potentially biasing the analysis (see Section 5.3).

The data are grouped by calendar year (a categorical variable with values 75, 76, ... , 86), number of doors (a discrete linear variable with value 2 or 4) and by class intervals of vehicle age (0-2, 3-5, 6-8, 9-12, 13-15, 16+ years), track width (45-47, ... , 64-66 inches) and curb weight (1600-2399, ... , 4800-5599 pounds). Wheelbase is not used, since the other two size parameters were found in Chapter 5 to be sufficient for this calibration regression. The additional n of doors variable (not used in Chapter 5), doubles the number of cells and adding wheelbase would make too many cells. The dependent variable is the log of the odds ratio of rollover ejection fatalities to fixed object fatalities. The independent variables are calendar year (categorical) and n of doors, age, track width and curb weight (all linear). There are 478 data points. The data points are weighted according to the number of rollover ejection fatalities in that group.

In the regression, each of the independent variables had a significant effect except vehicle age, which had virtually no effect. As a result, it became possible to rerun the regression without the age variable. The regression coefficients are:

INTERCEPT	3.50	N of DOORS	- .086
TRACK WIDTH	- .052	CURB WEIGHT	- .00019

CY75	-.435	CY79	-.211	CY83	-.098
CY76	-.441	CY80	-.103	CY84	-.087
CY77	-.309	CY81	+.033	CY85	-.200
CY78	-.366	CY82	-.174		

The CY86 term is implicitly zero, since the terms for the other calendar years are measured relative to 1986. R squared is .60, an adequate correlation. Essentially, the model says that rollover ejections were sharply underreported (or less common, or both) in calendar years 1975-76 and, to a lesser extent, in 1977-78 relative to 1979-86. That is consistent with the visual information in Figure 6-1.

For the regression of nonejection fatality risk, the regression is further limited to cars of model years 1968-79 <u>that had B pillars</u>. Since Standard 216 (Roof Crush Resistance) took effect in 1974, in the middle of the critical 1968-79 period, there is no way the regression can be limited to post-Standard cars, as was done for the ejections. Instead, the regression is limited to pillared vehicles, since their roof crush resistance changed little before and after Standard 216 (see Chapters 3 and 4). The data are tabulated by calendar year, model year, make/model code and number of doors (2 or 4). The 1968 Volkswagen is again excluded from the regression.

The data are grouped by calendar year and by class intervals of vehicle age, track width and curb weight. The dependent variable is the log of the odds ratio of rollover nonejection fatalities to fixed object fatalities. The independent variables are calendar year (categorical), age, track width and curb weight (all linear; the values used are the midpoints of the class intervals). There are 306 data points. The data points are weighted according to the number of rollover nonejection fatalities in that group.

Here, the vehicle age variable had a significant effect. The regression coefficients are:

INTERCEPT	1.47	CURB WEIGHT	.000007
TRACK WIDTH	- .045	VEHICLE AGE	.031

CY75	-.053	CY79	+.279	CY83	-.048
CY76	-.007	CY80	+.190	CY84	-.045
CY77	+.140	CY81	+.281	CY85	-.075
CY78	-.023	CY82	+.120		

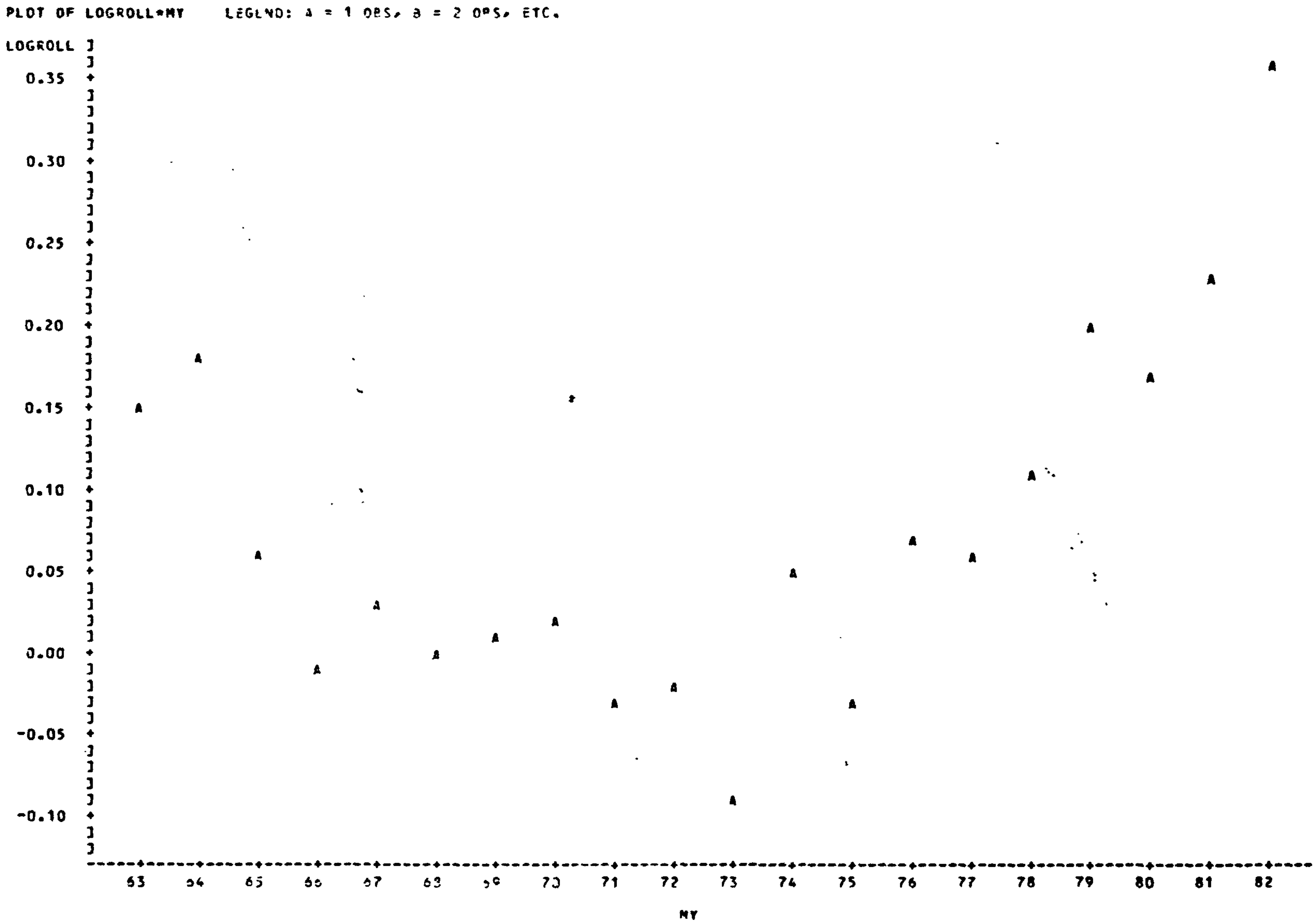
The CY86 term is implicitly zero. R squared is .34, lower than before because nonejection rollover fatalities are rarer than ejections and the cells are sparser. Essentially, the model says that rollover nonejections were overreported (or more common, or both) in calendar years 1979-82, relative to 1975-78 and 1983-86, consistent with Figure 6-2. Although the visual information in Figure 6-2 seems to show that they were underreported in 1975-76, the regression indicates that this is a vehicle age effect rather than a calendar year effect.

Finally, the calendar year corrections are achieved by dividing the reported number of rollover fatalities (ejection or nonejection) by the antilog of the appropriate regression coefficient, as explained in Section 5.2. The corrected data can be pooled across calendar years. Henceforth, the log odds ratios of rollover ejections to fixed object fatalities, after correction for calendar year, are called LOGR206, because an ultimate goal is to study the effect of improvements to door locks and retention components in response to Standard 206. The corrected log odds ratios for nonejection rollovers are called LOGR216 (named after Standard 216 - Roof Crush Resistance).

6.3 Simple models: no control for vehicle factors

The analysis now returns to the full FARS data set, including cars of model years 1963-82, sedans as well as hardtops. Figure 6-3 shows the overall trend in rollover fatality risk. Ejection and nonejection fatalities, each corrected for calendar year, are summed. The dependent variable LOGROLL is the log odds ratio of rollover fatalities to frontal fixed object impact fatalities. There have been major changes in the ratio during the 1963-82 period. In model year 1963-64, the log odds ratio is about .17, corresponding to 118 rollover fatalities per 100 fixed object fatals. By model year 1971-73, the ratio had decreased to -.05, or 95 rollovers per 100 fixed object fatals. From 1974 onwards, it increases sharply and exceeds the 1963-64 levels in cars of the early 1980's. The steady rise after 1974 coincides with the shift to smaller cars and

FIGURE 6-3: LOG ODDS RATIO OF <u>OVERALL</u> ROLLOVER FATALITIES TO FRONTAL FIXED OBJECT IMPACT FATALITIES, BY MODEL YEAR



downsizing of existing car lines. From Figure 6-3 it is not possible to recognize whether the improvement during 1963-70 is due to crashworthiness changes.

The same trends appear when ejections and nonejections are graphed separately. Figure 6-4 is a graph of LOGR206, the log odds ratio of ejection rollover fatalities to fixed object frontals. Figure 6-5 shows LOGR216, the corresponding ratio for nonejections. Since there are fewer nonejection fatalities, the cell sizes are smaller and Figure 6-5 shows more random variation than Figure 6-4.

6.4 Rollover fatality risk by market class

The trend in rollover fatality risk is more easily understood if the passenger car fleet is split into market classes and the various classes separately analyzed. That will provide a combined cross sectional and time series analysis. Also, since individual market classes tend to contain a set of cars, drivers and driving environments that change relatively little from year to year, the effect of changes in vehicle design should be more readily apparent.

The same 7 market classes defined in Section 5.4 are used throughout the analysis:

1. Volkswagens
2. All imports other than Volkswagens
3. Domestic subcompacts
4. Domestic compacts
5. Domestic intermediates
6. Large domestic cars
7. Sporty domestic cars

FIGURE 6-4: LOG ODDS RATIO OF ROLLOVER EJECTION FATALITIES TO FRONTAL FIXED OBJECT IMPACT FATALITIES, BY MODEL YEAR

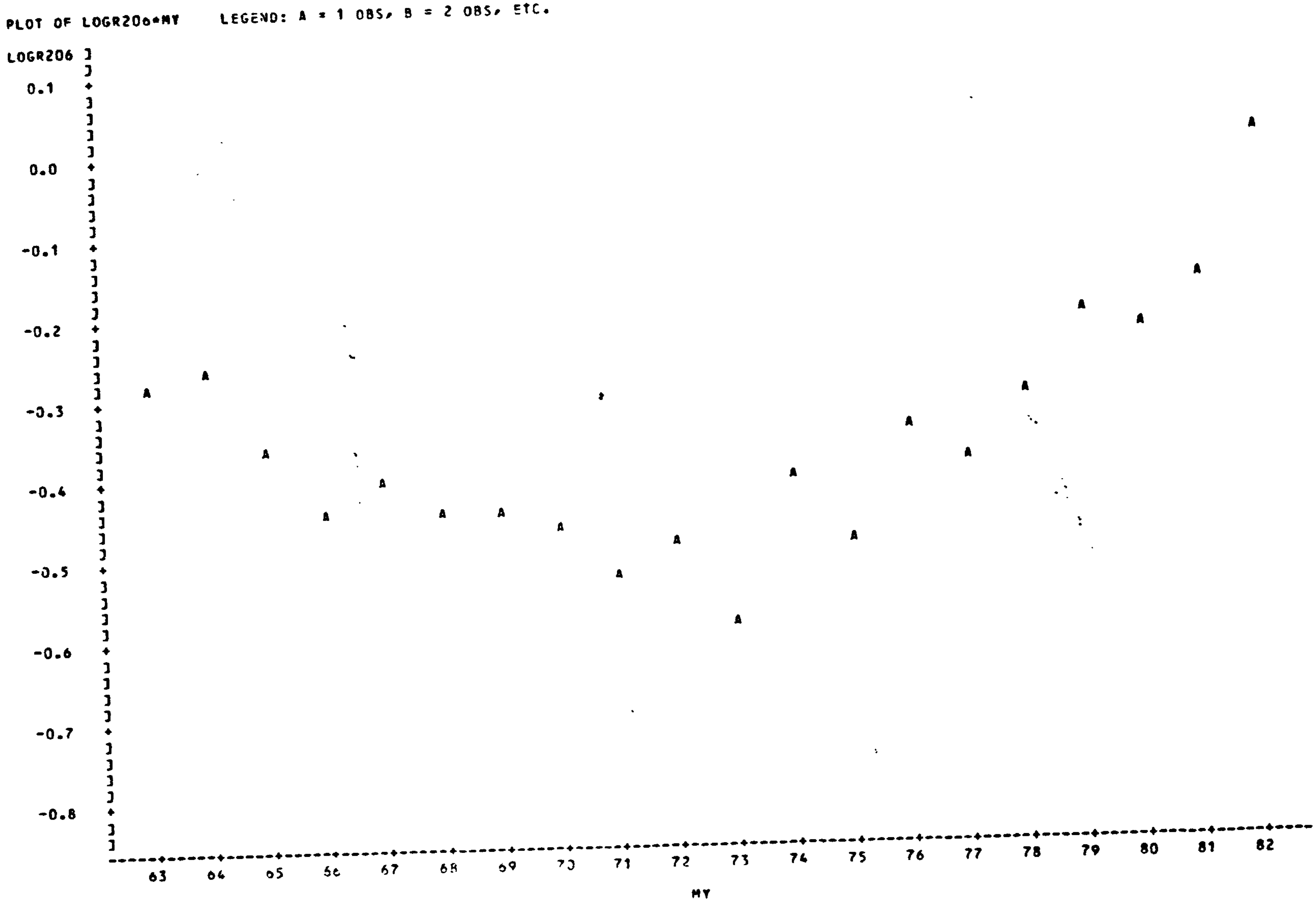
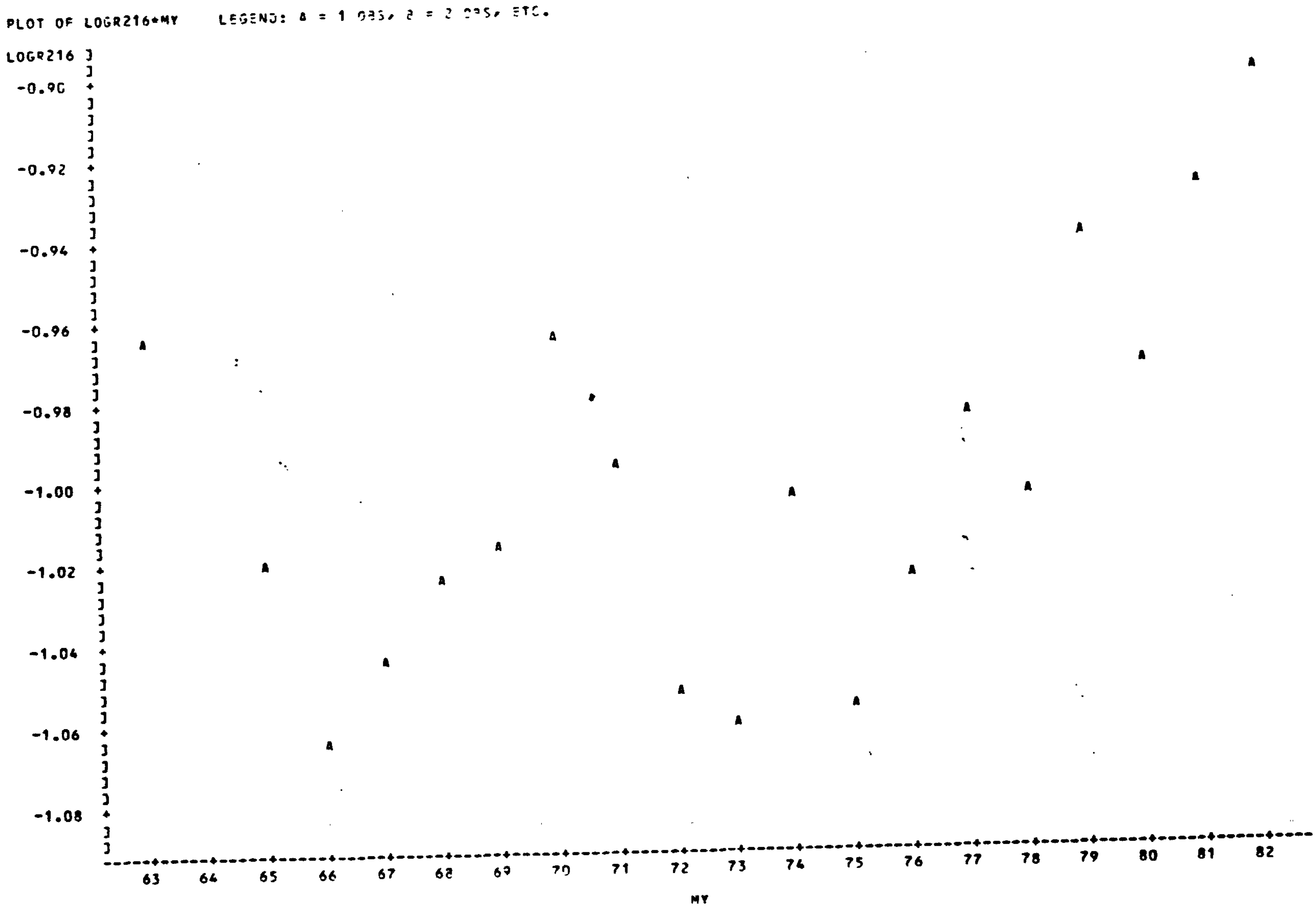


FIGURE 6-5: LOG ODDS RATIO OF ROLLOVER <u>NONEJECTION</u> FATALITIES TO FRONTAL FIXED OBJECT IMPACT FATALITIES, BY MODEL YEAR



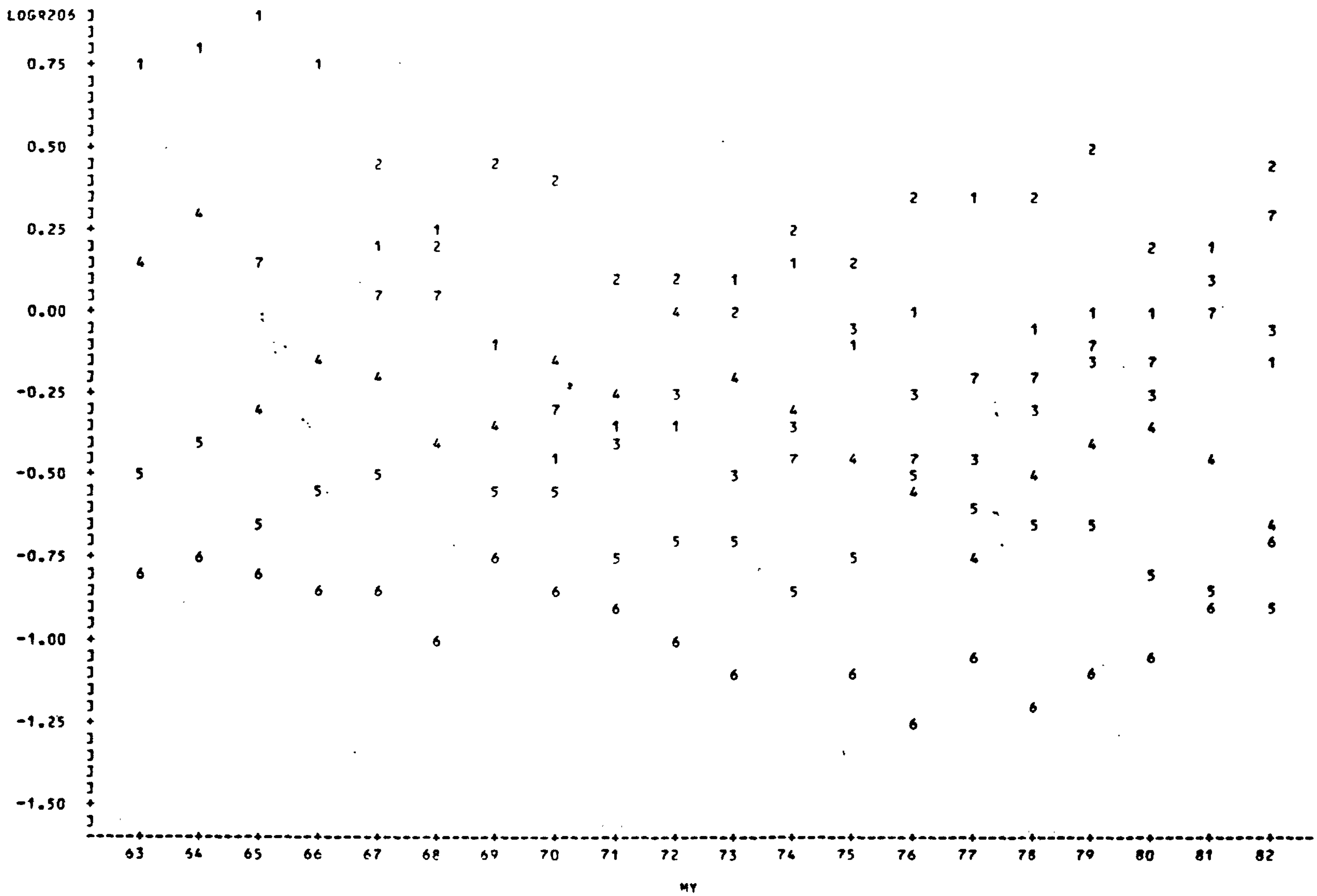
The data were grouped by market class and model year. Figure 6-6 is a graph of LOGR206, the ejection fatality risk, while Figure 6-7 shows LOGR216, the nonejection fatality risk. In each case, the numbers on the graph represent the market class.

The most obvious fact is that the differences between market classes far exceed the year to year changes within market classes. Imported cars - classes 1 and 2 - have a values of LOGR206 close to .3, corresponding to 135 rollover ejection fatalities per 100 fixed object fatalities. Large domestic cars - class 6 - have values of LOGR206 close to -1, corresponding to 37 ejection fatalities per 100 fixed object fatals. That is a 3.5 to 1 difference in rollover fatality risk.

Nevertheless, the discrepancy between small and large car fatalities is only half as large as on the nonfatal rollovers, where it was 7 to 1 (see Section 5.4 and Figures 5-3A and 5-3B). Figures 5-3A, 5-3B and 6-6 reveal paradoxical facts about rollover frequency and severity. The least stable cars (high rollover frequency) can roll over even in crashes of low severity. As a result, they have the lowest fatality rate per 100 rollovers, even though they have the highest fatality rate per unit of exposure (100 car years - or 100 fixed object fatals). "Fatalities per 100 rollovers" is a misleading measure of risk because it is confounded by rollover propensity. For example, small cars have half the fatality risk per 100 rollovers as large cars, but 7 times the rollover frequency, resulting in a 3.5 to 1 ratio of fatality risk per unit of exposure. Chapter 7 will explore the issue of fatality rates per rollover in detail.

FIGURE 6-6: ROLLOVER EJECTION FATALITY RISK BY MODEL YEAR AND MARKET CLASS

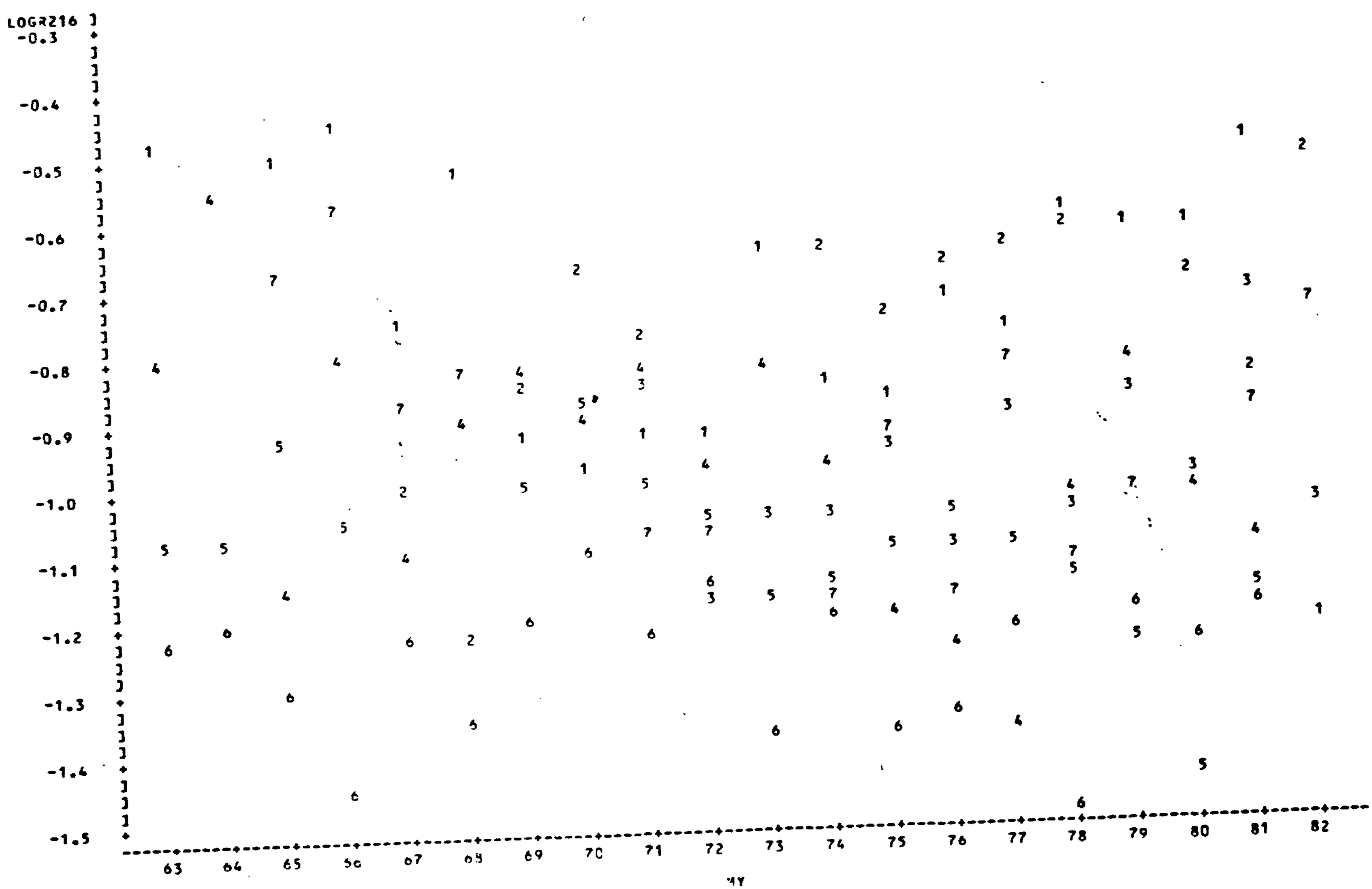
PLOT OF LOGR205*MY   SYMBOL IS VALUE OF CARGP



NOTE: 10 OBS HIDDEN

FIGURE 6-7: ROLLOVER NONEJECTION FATALITY RISK BY MODEL YEAR AND MARKET CLASS

PLOT OF LOGR216*MY   SYMBOL IS VALUE OF CARGP



NOTE: 11 OBS HIDDEN

In general, Figure 6-6 shows the same patterns for market classes as Figures 5-3A and 5-3B did for the nonfatal rollovers. Volkswagens, as indicated by the "1's" on the graphs, had an exceptionally high ejection risk in the mid 1960's. They have as many as 220 rollover ejections per 100 fixed object fatals, which is 65 percent higher than the rate of other small cars. But the situation improves in 1967-69 and subsequently is about the same as for other imported cars. Imported cars other than Volkswagens (class 2) have a nearly uniform, high ejection risk, followed by domestic subcompacts (class 3), compacts (class 4), and intermediates (class 5). Large domestic cars (class 6) have consistently low ejection risk.

Sporty domestic cars (class 7), on the other hand fare worse on ejection risk (just a little below imports) than on nonfatal rollover rates (better than domestic compacts). The primary reason appears to be that all the sporty cars have 2 doors, resulting in higher ejection risk than the other classes, which are a mix of 2 and 4 door cars. At first glance, an additional factor might be that these cars have unusually severe crashes.

Figure 6-7, the graph of nonejection rollover fatality risk, shows the same trends as the ejections, although there is more "noise" in the graph due to the smaller cell sizes. Small cars have LOGR216 values close to -.6, corresponding to 55 nonejection rollover fatalities per 100 fixed object fatals. Large cars have values close to -1.3, corresponding to 27 nonejection fatals per 100 fixed object fatals. Here, even more than for the ejectees, the fatality rate per 100 rollovers is confounded with rollover propensity. Since it takes a really severe rollover to produce a fatality within the vehicle, small cars (which can roll over in minor crashes) have only 1/3.5 as many nonejection fatalities per 100 rollovers as large cars. Since small cars roll over 7 times as often, that multiplies out to 2 times as many nonejection fatalities per unit of exposure.

Figure 6-7 also shows that sporty domestic cars have relatively low risk of nonejection fatalities - about the same as domestic compacts and intermediates and about the same as their rank on nonfatal rollover rates. That would suggest that the high ejection risk for sporty cars is primarily because they have 2 doors, not because their crashes are unusually severe. The nonejection rate for early Volkswagens is higher than for other cars, but not nearly to the extent that they are overinvolved in nonfatal rollovers or in ejections: that attests to the low severity of the crashes and the exceptional roof crush strength of the Beetle (see Chapters 3 and 4).

6.5 Models of rollover ejection risk

So far, the trends in rollover ejection risk per 100 frontal fatalities primarily reflect changes in rollover propensity. What is really desired, though, is a measure of the trend in crashworthiness or "ejection resistance." It has already been shown that the ejection fatality rate per 100 rollovers is not a valid measure of crashworthiness, since it, too, is confounded with rollover propensity. Instead, it is better to work with the ejection risk per 100 frontal fatalities, but to filter out the effects of factors that are correlated with rollover frequency. That would leave only the crashworthiness effects. Among those, it is desirable to distinguish between vehicle modifications made primarily in response to consumer demand - the mix of 2 door and 4 door cars - vs. those primarily made for safety reasons, such as improved door locks.

Fortunately, the analyses of Section 5.5 already identified important "factors that are correlated with rollover frequency." Except for the pre-1969 Volkswagen, rollover frequency is highly correlated with vehicle size parameters such as track width, curb weight, or wheelbase. Thus, the crashworthiness trend can be obtained by excluding the pre-1969 Volkswagens from the analysis and controlling for the vehicle size parameters.

The first step is a logistic regression of rollover ejection risk by 4 vehicle size parameters (track width, curb weight, wheelbase and car height) and 2 crashworthiness parameters (number of doors and door lock status). The data points for the regression are the combinations of model year (1963-82), market class (1-7, as defined in the preceding section), and number of doors (2 or 4), but excluding the Volkswagens from 1968 and earlier. There are 201 data points. The approach here differs from Sections 5.5 and 6.2, since the data are not pooled across model year and market class; model year identity needs to be maintained to permit definition of the STD206 variable (see below).

For each data point, the average values of track width, curb weight, wheelbase and car height are computed from the accident cases that constitute the data point. For example, if there are 900 1966 Mustangs (car height 51 inches) and 100 1966 Barracudas (height 53 inches) on the file, the average height of sporty domestic 1966 cars is 51.2 inches. The dependent variables is LOGR206, the corrected log odds ratio of ejections to fixed object fatals. The independent variables are the data points' average values of track width, curb weight, wheelbase and car height; the number of doors (2 or 4) and STD206, the door lock status. Since door lock, latch and hinge improvements were introduced gradually during model years 1963-68, with little change after 1968 [30], [31] STD206 is set to zero for model year 1963, .2 in 64, .4 in 65, .6 in 66, .8 in 67 and 1 from 1968 onward. Vehicle age is not included among the variables since it was found to have little or no effect in Section 6.2. The data points are weighted according to the number of actual, observed FARS cases in that group.

In the initial regression, wheelbase did not add significantly to multiple R squared. Since track width, curb weight, wheelbase and other vehicle size parameters are all highly intercorrelated, it is conceivable that a multiple regression model could assign effects to one of these variables that should partly have been assigned to another, even to the point where the effect of the first variable loses statistical significance. Car height had a borderline significant effect, but in the wrong direction: taller cars had lower ejection risk. Since car height was not significant in any of the regressions of Chapter 5, the effect here is believed to be spurious and the result of intercorrelation: wider, heavier cars roll over less and also tend to be taller. Wheelbase and height were eliminated from the models. With the remaining variables, the regression coefficients are:

INTERCEPT	4.212	TRACK WIDTH	- .0614
CURB WEIGHT	- .000188		
STD206	- .119	N of DOORS	- .122

R squared is .77, an adequate correlation. The model suggests that cars meeting Standard 206 have exp(-.119) = 11 percent lower ejection risk than model year 1963 cars (other than Volkswagens), after controlling for the other factors. The reduction, however, is not statistically significant since the t value for the regression coefficient is 1.02. Two door cars have exp(2 x .122) = 28 percent higher ejection risk than 4 door cars, after controlling for the other factors. The difference is statistically significant (t = 6.15). The model says that rollover ejection risk decreases as cars get wider and heavier. Track width, however, has by far the highest correlation. For a typical car with a track width of 55 inches and curb weight of 3000 pounds, a 1 percent increase in track width is associated with a .0614(.55) = 3 percent decrease in rollover ejection fatality risk. A 1 percent increase in curb weight is associated with a .000188(30) = 0.6 percent decrease in risk.

The validity of these results was checked by using a quite different regression procedure, similar to the one employed with Texas data (Section 5.5). The data are aggregated across car groups and model years (1971 and later) and tabulated by class intervals of track width, curb weight, wheelbase, car height and/or vehicle age, as in Section 5.5, and also by class intervals of driver age and by number of doors. In general, these regressions showed the same effects as the preceding ones, except that in some cases the effect of wheelbase was stronger and track width and/or curb weight proportionately weaker. Driver age had significant correlation with the dependent variable and its inclusion in the model made the vehicle age term nonsignificant, yet had little or no influence on the track width, wheelbase and curb weight terms. In the FARS data, the correlation between track width and wheelbase is .913, between track width and curb weight, .922, and between wheelbase and curb weight, .932. Thus, it is easy for the regression models to confuse the relative importance of those three variables - but they will accurately predict the combined effect of the three variables and the difference in rollover risk between the "typical" small car and the "typical" large car. On the other hand, the correlations between driver age and track width, wheelbase and curb weight are only .122, .184 and .149. That is why the inclusion or exclusion of driver age in the model has little influence on the coefficients of the three vehicle size parameters.

The next step is to use the regression coefficients to adjust the rollover rates by model year, market class and n of doors. For each data point, define

ADJ206 = LOGR206 + .0614 TRACK WIDTH + .000188 CURB WEIGHT
+ .122 N of DOORS

and

ADJ306 = LOGR206 + .0614 TRACK WIDTH + .000188 CURB WEIGHT

For cars other than old Volkswagens, ADJ306 filters out factors that influence rollover frequency and measures the trend in "ejection resistance" or crashworthiness of cars. ADJ206 further adjusts for the number of doors, a crashworthiness factor largely dictated by market demand and beyond the control of the safety engineer. It is the most intrinsic measure of the safety trend of cars, in the context of rollover ejections.

Figure 6-8 displays the fully adjusted ejection risk ADJ206 by market class and number of doors. The numbers 1-7 on the graph represent <u>2 door cars</u> of those market classes; "8" denotes large domestic 4 door cars; "9" is intermediate domestic 4 door cars; "0" includes compact, subcompact and imported 4 door cars. It is evident that the adjustment procedure removes most of the differences between market classes. The band width for ADJ206 is only about one third as wide as for LOGR206 (Figure 6-6). Large 4 door cars, which had the lowest ejection risk prior to adjustment, have adjusted rates anywhere from the top to the bottom of the band, as denoted by the 8's in Figure 6-8. Sporty domestic cars (7) and imported 2 door cars (2) tend to be on the high side, but usually within the pack or close to it.

The last step of the modeling process is to aggregate the data points in Figure 6-8 across market classes/number of doors and obtain an estimate of the average intrinsic ejection risk by model year. Figure 6-9 shows ADJ306, the overall crashworthiness trend including the effect of market shifts between 2 and 4 door cars. It shows little net change in ejection risk during the 1963-82 period. Note that most of the points are between 3.75 and 3.85 on the vertical axis - i.e., in a bandwidth of just

FIGURE 6-8: ROLLOVER EJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE, WEIGHT AND N OF DOORS, BY MODEL YEAR, MARKET CLASS AND N OF DOORS (Excluding Pre-1969 VW)
(1-7 = 2 door car of that market class; 8 = full-sized 4 door;
9 = intermediate 4 door; 0 = compact, subcompact or imported 4 door)

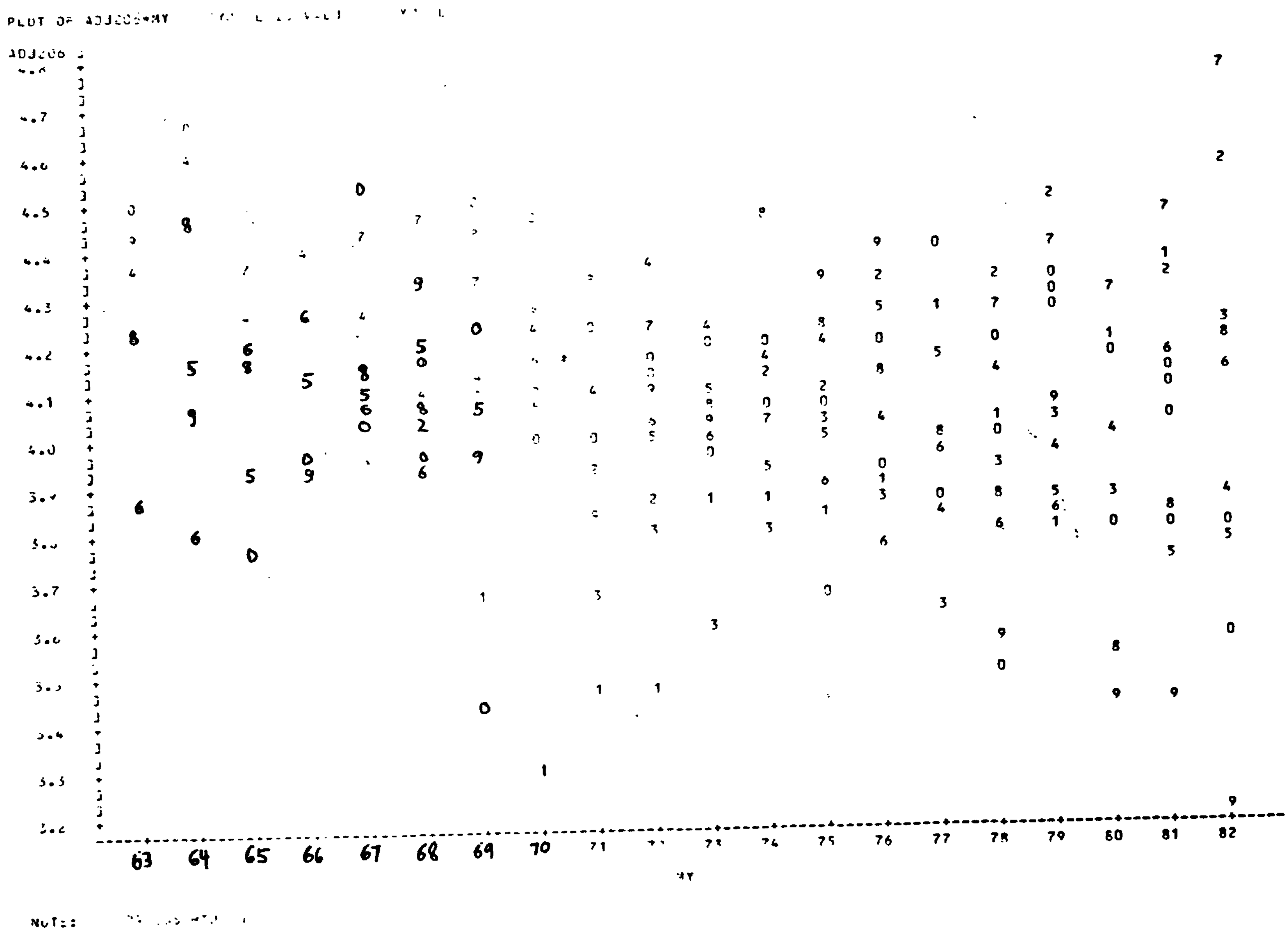
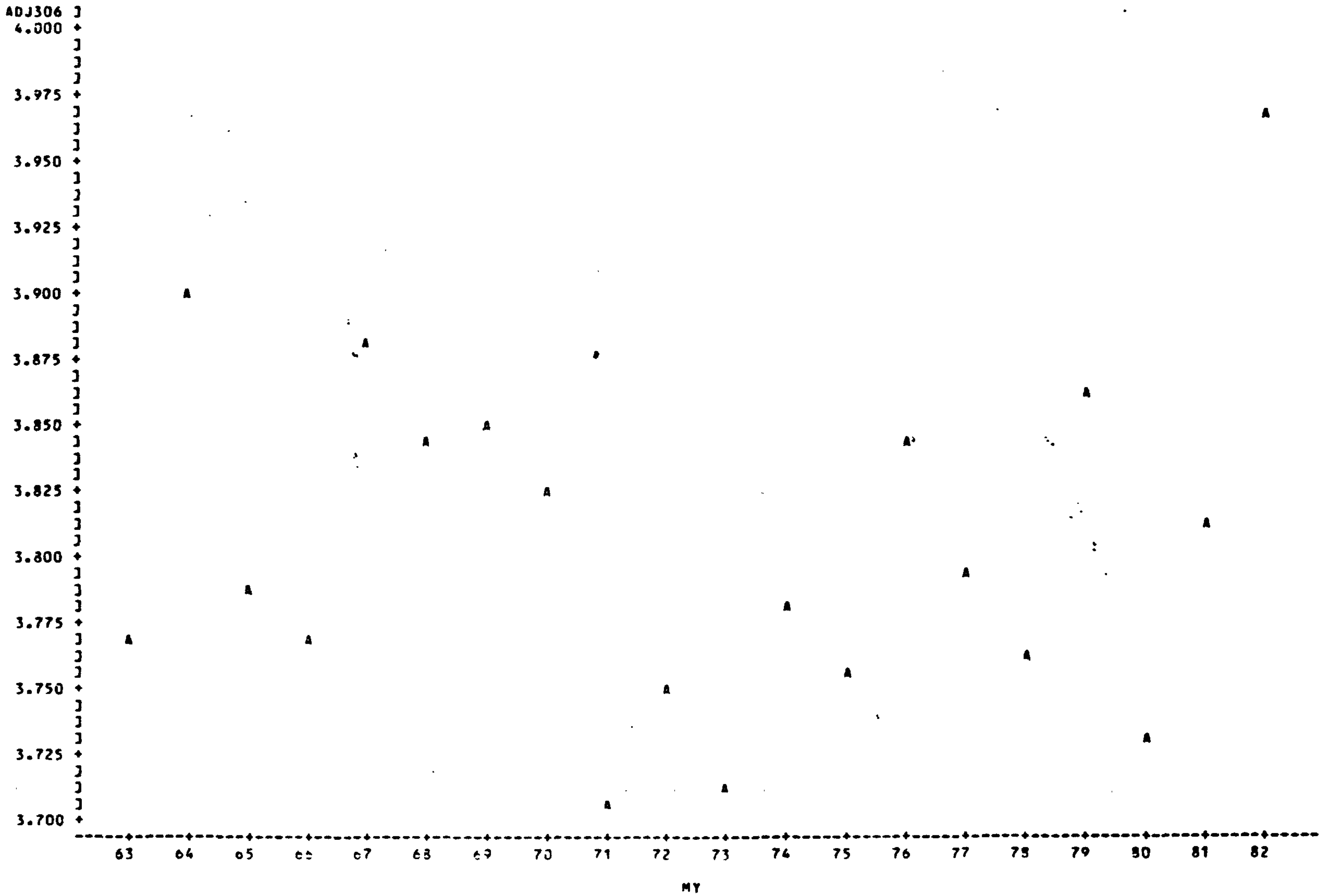


FIGURE 6-9: ROLLOVER EJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR (Excluding Pre-1969 VW)

ADJUSTED EJECTION RATE EXCLUDING OLD VOLKSWAGENS

PLOT OF ADJ306*MY LEGEND: A = 1 OBS, B = 2 OBS, ETC.



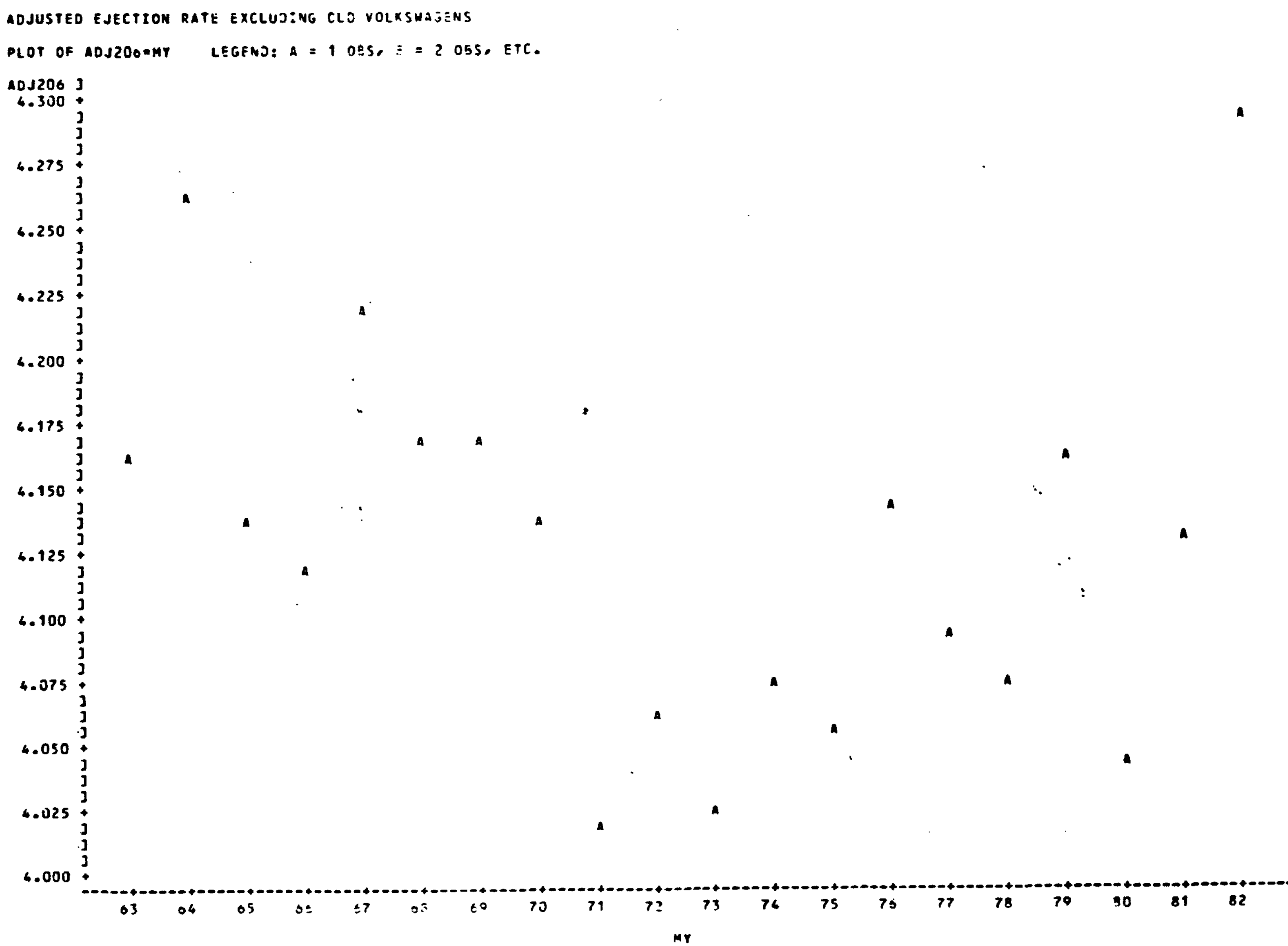
10 percent variation of ejection risk. The year to year variations are small, even though they look large because of the graph's large scale. The variations have no obvious pattern and are essentially "noise."

Figure 6-10 depicts ADJ206, the "intrinsic" safety trend, which measures the effect of all crashworthiness changes <u>other than</u> market shifts between 2 and 4 door cars. Here, the picture is more favorable. There appears to be a borderline significant reduction of ejection risk during the mid 1960's, which levels out (at best) from 1970 onwards. The net reduction, as measured on the vertical axis, seems to be from about 4.2 in the early 1960's to slightly below 4.1 in cars of the 1970's - corresponding to just over 10 percent reduction of ejection risk during the time that door locks, latches and hinges were improved in American cars.

Figures 6-9 and 6-10 in combination indicate that the benefits of improved door locks, implemented during the mid 1960's, were largely dissipated by the substantial shift from 4 door to 2 door cars during 1963-74 (see Section 1.5).

A shortcoming of the preceding models is that early Volkswagens had to be excluded, since their changes in rollover propensity cannot be attributed to track width and curb weight alone. But these cars accounted for a high proportion of all rollovers <u>and</u> received major door lock improvements during the 1960's. [11], [32], [34]. Excluding them leads to an underestimate of the benefits of Standard 206. Chapter 7 develops models of ejection risk which include the older Volkswagens.

FIGURE 6-10: ROLLOVER EJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE, WEIGHT AND N OF DOORS, BY MODEL YEAR (Excluding Pre-1969 VW)



6.6 Models of rollover nonejection risk

The trend in crashworthiness of the vehicle interior during a rollover - the fatality risk on nonejected occupants after filtering out the effects of factors that change rollover propensity - is analyzed by similar methods as the ejection risk. The trend should be analyzed separately for true hardtops and sedans. Chapters 3 and 4 showed that Standard 216 had little effect on sedans, while true hardtops were strengthened or converted to a pillared hardtop design.

The first step is a logistic regression of rollover nonejection risk by 4 vehicle size parameters (track width, curb weight, wheelbase and car height), 2 crashworthiness parameters (presence of B pillar and Standard 216 status), and vehicle age (which did have a significant effect in the regression of nonejections in Section 6.2). The data points for the regression are the combinations of model year (1963-82), market class (1-7, as defined in the preceding section), and B pillar status (yes or no), but excluding the Volkswagens from 1968 and earlier. There are 150 data points.

For each data point, the average values of vehicle age, track width, curb weight, wheelbase and car height are computed from the accident cases that constitute the data point. The dependent variables is LOGR216, the corrected log odds ratio of nonejections to fixed object fatals. The independent variables are the data points' average values of vehicle age, track width, curb weight, wheelbase and car height; B pillar presence (0 = hardtop, 1 = sedan) and STD216. Since roofs may have been strengthened as early as 1971 [56], but some hardtops had difficulty meeting Standard 216 as late as 1974 (see Section 3.4), STD216 is set to zero until model year 1970, .2 in 71, .4 in 72, .6 in 73, .8 in 74 and 1 from 1975 onward. Since Chapters 3 and 4 suggest that Standard 216 had different effects on hardtops and sedans, the B pillar x STD216 interaction term is also included as an independent variable. The data points are weighted according to the number of actual, observed FARS cases in that group.

In the initial regression, vehicle age and wheelbase did not add significantly to multiple R squared. Apparently, the vehicle age effect was subsumed by the calendar year correction of Section 6.2. Since track width, curb weight, wheelbase and other vehicle size parameters are all highly intercorrelated, it is conceivable that a multiple regression model could assign effects to one of these variables that should partly have been assigned to another, even to the point where the effect of the first variable loses statistical significance. Car height had a borderline significant effect, but in the wrong direction: taller cars had lower nonejection risk. Since car height was not significant in any of the regressions of Chapter 5, the effect here is believed to be spurious and the result of intercorrelation: wider, heavier cars roll over less and also tend to be taller. Vehicle age, wheelbase and height were eliminated from the models. With the remaining variables, the regression coefficients are:

INTERCEPT	0.806	TRACK WIDTH	- .0227
CURB WEIGHT	- .000119		
STD216	- .218	B pillar	- .140
STD216 x B	+ .218		

R squared is .59, an adequate correlation. The model suggests that hardtops meeting Standard 216 have exp(-.218) = 20 percent lower nonejection fatality risk than pre-1971 hardtops, after controlling for the other factors. The reduction is not statistically significant (t = 2.24). But Standard 216 had exp(-.218 + .218) = zero effect on sedans. Pre Standard 216 hardtops had exp(.140) = 15 percent higher nonejection risk in rollovers than sedans, after controlling for the other factors. The difference is statistically significant (t = 3.04). The model says that rollover nonejection risk decreases as cars get wider and heavier. Track width, however, has the highest correlation. For a typical car with a track width of 55 inches and curb weight of 3000 pounds, a 1 percent increase in track width is associated with a .0227(.55) = 1.2 percent decrease in rollover nonejection fatality risk. A 1 percent increase in curb weight is associated with a .000119(30) = 0.4 percent decrease in risk.

The validity of these results was checked by using a quite different regression procedure, in which the data are aggregated across car groups and model years (1971 and later) and tabulated by class intervals of track width, curb weight, wheelbase, car height and/or vehicle age, and driver age. In general, these regressions showed the same effects as the preceding ones, except that in some cases the effect of wheelbase was stronger and track width and/or curb weight proportionately weaker. Driver age had significant correlation with the dependent variable and its inclusion in the model made the vehicle age term nonsignificant, yet had little or no influence on the track width, wheelbase and curb weight terms.

The next step is to use the regression coefficients to adjust the rollover rates by model year, market class and B pillar presence. For each data point, define

ADJ216 = LOGR216 + .0227 TRACK WIDTH + .000119 CURB WEIGHT
+ .140 B pillar presence

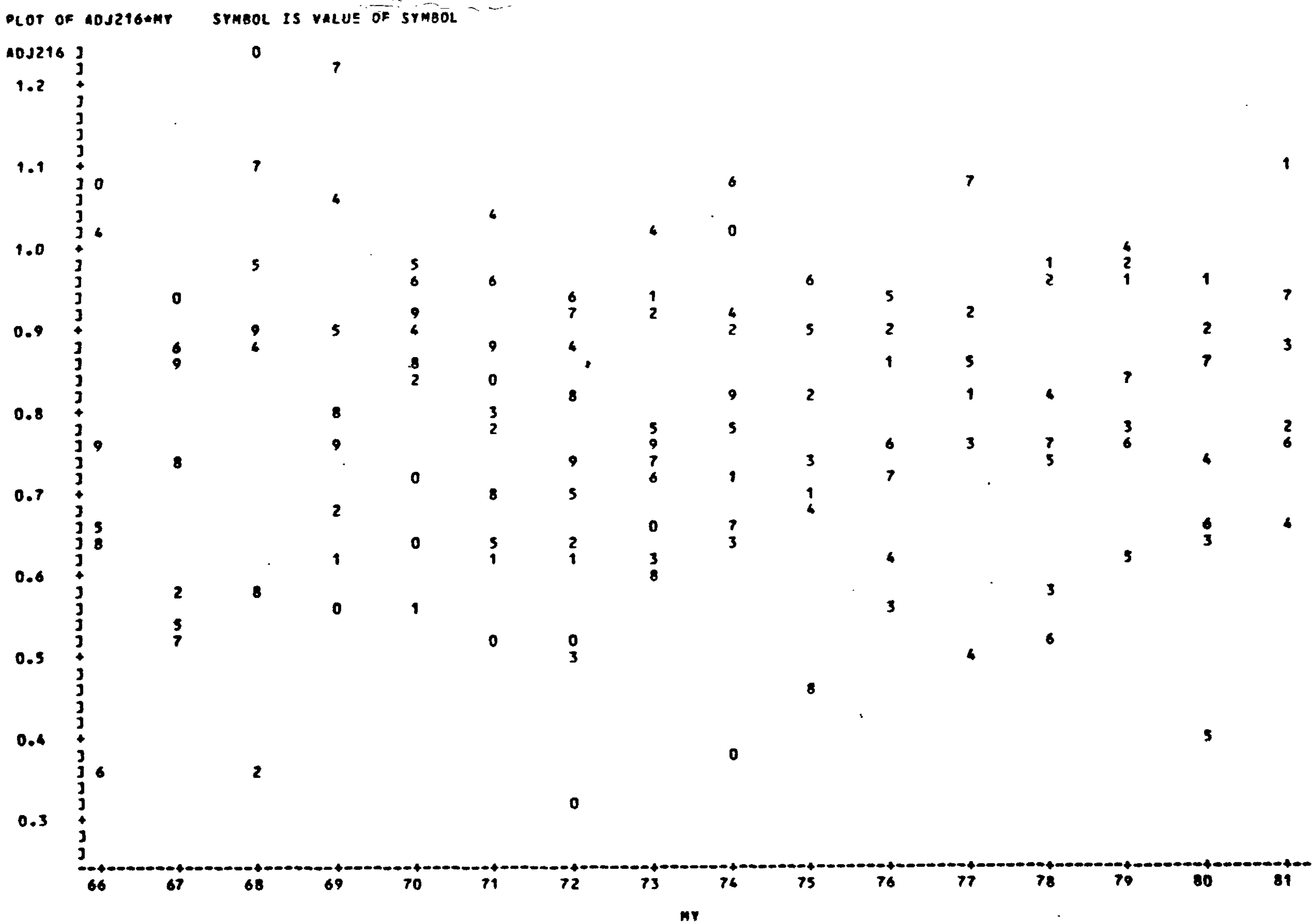
and

ADJ316 = LOGR216 + .0227 TRACK WIDTH + .000119 CURB WEIGHT

For cars other than old Volkswagens, ADJ316 filters out factors that influence rollover frequency and measures the trend in the crashworthiness of car interiors during rollovers. ADJ216 further adjusts presence or absence of B pillars. Here, ADJ316 is the more intrinsic measure of the safety trend of cars, unlike the ejection case, where ADJ206 was better. In the ejection case, market shifts between 2 and 4 door cars are primarily due to consumer demand and outside the manufacturers' control. Here, the shift from true to pillared hardtops was actively initiated by the manufacturers. Even if styling rather than safety was an initial motivation, it turns out, in effect, to have been the primary vehicle modification to increase roof crush resistance. Therefore, it should be included among the "intrinsic" crashworthiness modifications of the 1963-82 period and not filtered out as an "external" factor.

Figure 6-11 displays the fully adjusted nonejection risk ADJ216 by market class and B pillar presence. The numbers 1-7 on the graph represent <u>sedans</u> of those market classes; "8" denotes large domestic hardtops; "9" is intermediate domestic hardtops; "0" denotes compact or sporty domestic hardtops. Model years 1963-65 and 1982 have been deleted from this and the remaining figures, since the sparse cells for those

FIGURE 6-11: ROLLOVER NONEJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE, WEIGHT AND B PILLAR STATUS, BY MODEL YEAR, MARKET CLASS AND B PILLAR STATUS (Excluding Pre-1969 VW)
(1-7 = pillared car of that market class; 8 = full-sized hardtop;
9 = intermediate hardtop; 0 = compact or sporty hardtop)



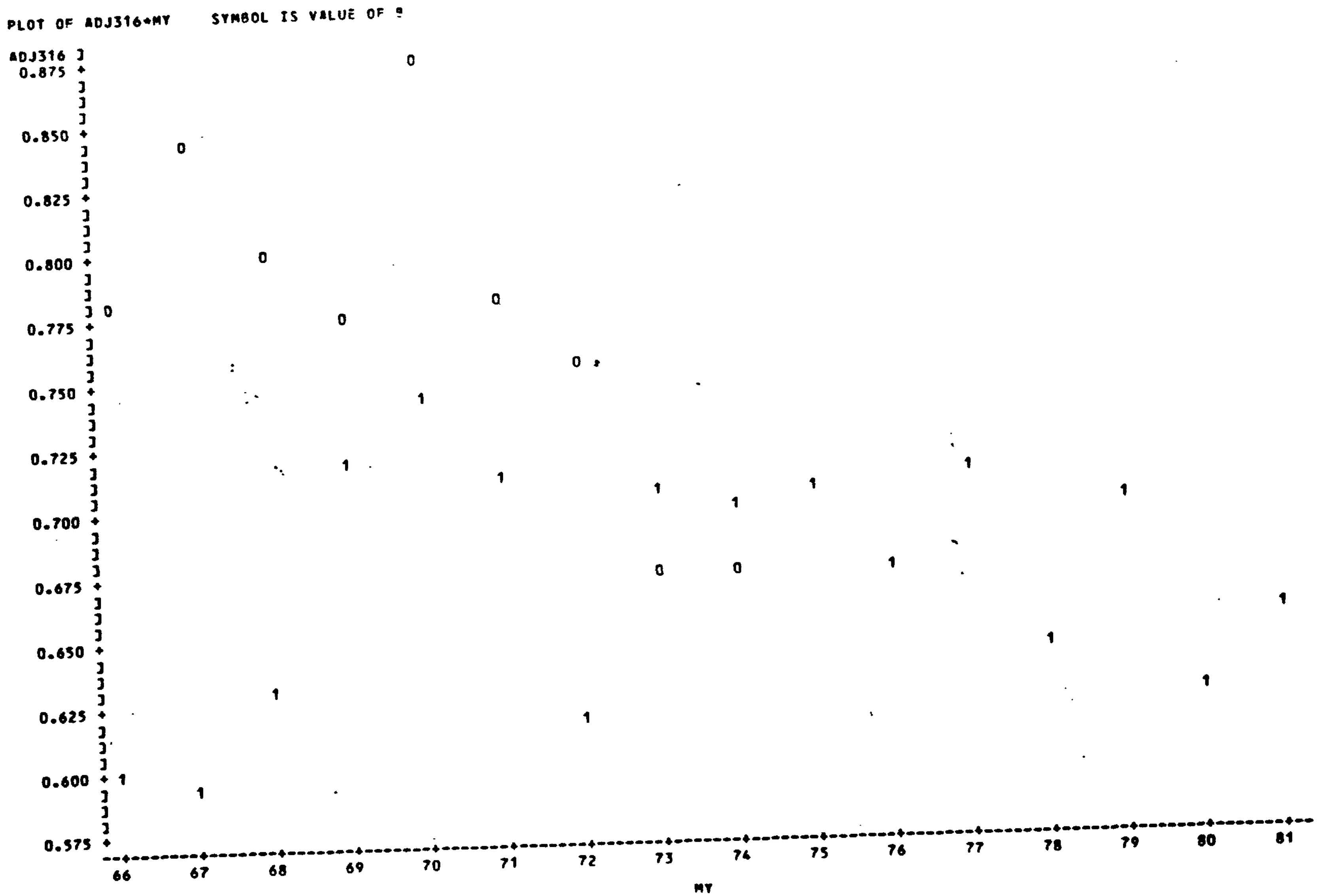
NOTE: 12 OBS HIDDEN

years have excessive sampling errors and outlying data points. It is evident that the adjustment procedure scrambled the market classes and mixed up the hardtops and sedans. The band width for ADJ216 is less than half as wide as for LOGR216 (Figure 6-7). Large sedans, which had the lowest nonejection risk prior to adjustment, have adjusted rates anywhere from the top to the bottom of the band, as denoted by the 6's in Figure 6-11. The few outlying points are presumably the consequence of sparse cells and sampling error, with one exception: the low rates for certain hardtops in 1972-75, indicated by 8's and 0's, show that they had lower risk than earlier hardtops of the same size.

In Figure 6-12, the values of ADJ316 are aggregated across market classes to obtain the crashworthiness trend for vehicle interiors during rollovers - separately for hardtops and sedans. True hardtops, indicated by 0's in Figure 6-12, had consistently larger fatality risk than sedans until the early 1970's, even after controlling for rollover frequency. But their crashworthiness in rollovers improved in the early 1970's and was about equal to sedans in 1973-74. The improvement, as measured on the vertical axis, seems to be from about 0.8 in the late 1960's to slightly below 0.7 by model years 1973-74 - corresponding to about 10 percent reduction of fatality risk. After model year 1974, few true hardtops were produced and cell sizes are too small for statistically reliable data points. The trend for sedans and pillared hardtops, shown by 1's in Figure 6-12, is nearly flat throughout model years 1966-81.

The results are consistent with the view that roof crush

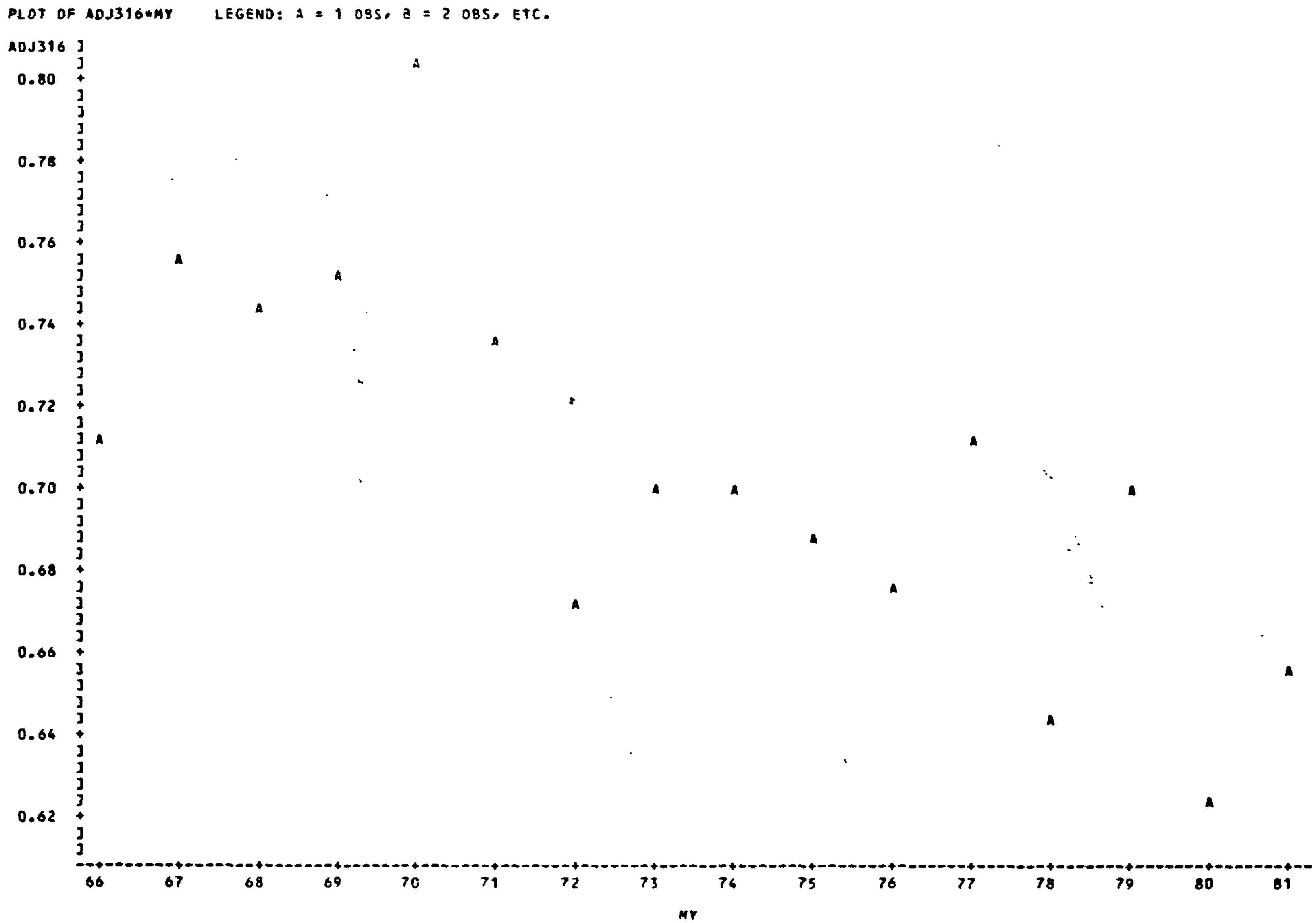
FIGURE 6-12: ROLLOVER NONEJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR AND B PILLAR STATUS (Excluding Pre-1969 VW)
(0 = true hardtop; 1 = sedan, pillared hardtop, etc.)



resistance is of at least some importance to occupant protection in interior impacts during rollovers. Hardtops had lower roof crush resistance than sedans, prior to Standard 216. During the years that Standard 216 was issued and took effect, true hardtops were strengthened or redesigned as pillared hardtops, resulting in lower fatality risk.

The last step of the modeling process is to aggregate the data points for sedans and hardtops and obtain an estimate of the average crashworthiness of car interiors during rollovers, by model year. Figure 6-13 shows that ADJ316 was consistently close to .75 during model years 1966-71. The risk decreased in the early 1970's and averaged around .67 after model year 1975 (although the noise in the graph makes it hard to pin down those numbers). That corresponds to roughly an 8 percent reduction of intrinsic fatality risk of persons not ejected in rollovers.

FIGURE 6-13: ROLLOVER NONEJECTION FATALITY RISK, ADJUSTED FOR CAR SIZE AND WEIGHT, BY MODEL YEAR (Excluding Pre-1969 VW)



CHAPTER 7

ANOTHER APPROACH TO STUDYING OCCUPANT PROTECTION IN ROLLOVERS

The Fatal Accident Reporting System data of Chapter 6 yielded a ratio of rollover fatalities to deaths in frontal impacts with fixed objects. Texas data in Chapter 5 provided a ratio of rollovers to frontal impacts with fixed objects. Dividing the FARS ratio by the Texas ratio gives an estimate of the fatality rate per 100 rollover crashes. That rate, however, is not a useful measure of occupant protection. Smaller cars roll over more frequently than large cars but their rollover crashes are less severe, on the average, than those of large cars. The more rollover-prone the car, the lower the fatality rate per 100 rollovers - but the higher the absolute number of rollover fatalities.

In Chapters 5 and 6, the effects of car size were eliminated by adjusting the rates based on <u>physical</u> attributes of cars, such as their track width and curb weight. Here, the approach is to identify purely <u>mathematical</u> combinations of the FARS and Texas ratios that are uncorrelated with a car's size or rollover proneness. These combinations measure the trend in occupant protection offered by cars in rollover crashes.

The analyses of this chapter suggest that the door lock, latch and hinge improvements of the mid to late 1960's reduced ejection fatalities in rollovers by approximately 18 to 24 percent. That is a higher estimate than the 10 percent found in Chapter 6. It is also a better one because it includes Volkswagens (which had to be excluded in Chapter 6 for the analysis to work). Volkswagens received major door lock improvements in the later 1960's and accounted for a disproportionate share of the cars in rollover crashes. Ejection fatality risk remained more or less constant after model year 1970, after controlling for changes in rollover proneness.

The fatality risk of persons who were not ejected in rollovers decreased by about 5 to 10 percent in the early to mid 1970's, the period when manufacturers shifted from true hardtops to pillared hardtops. That result coincides with the 8 percent reduction found by the method of Chapter 6.

The reductions in ejection and nonejection fatalities averages out to an overall improvement of 14 to 19 percent in the crashworthiness of passenger cars in rollovers during the 1963-82 era. About two thirds of the improvement had been achieved by model year 1968.

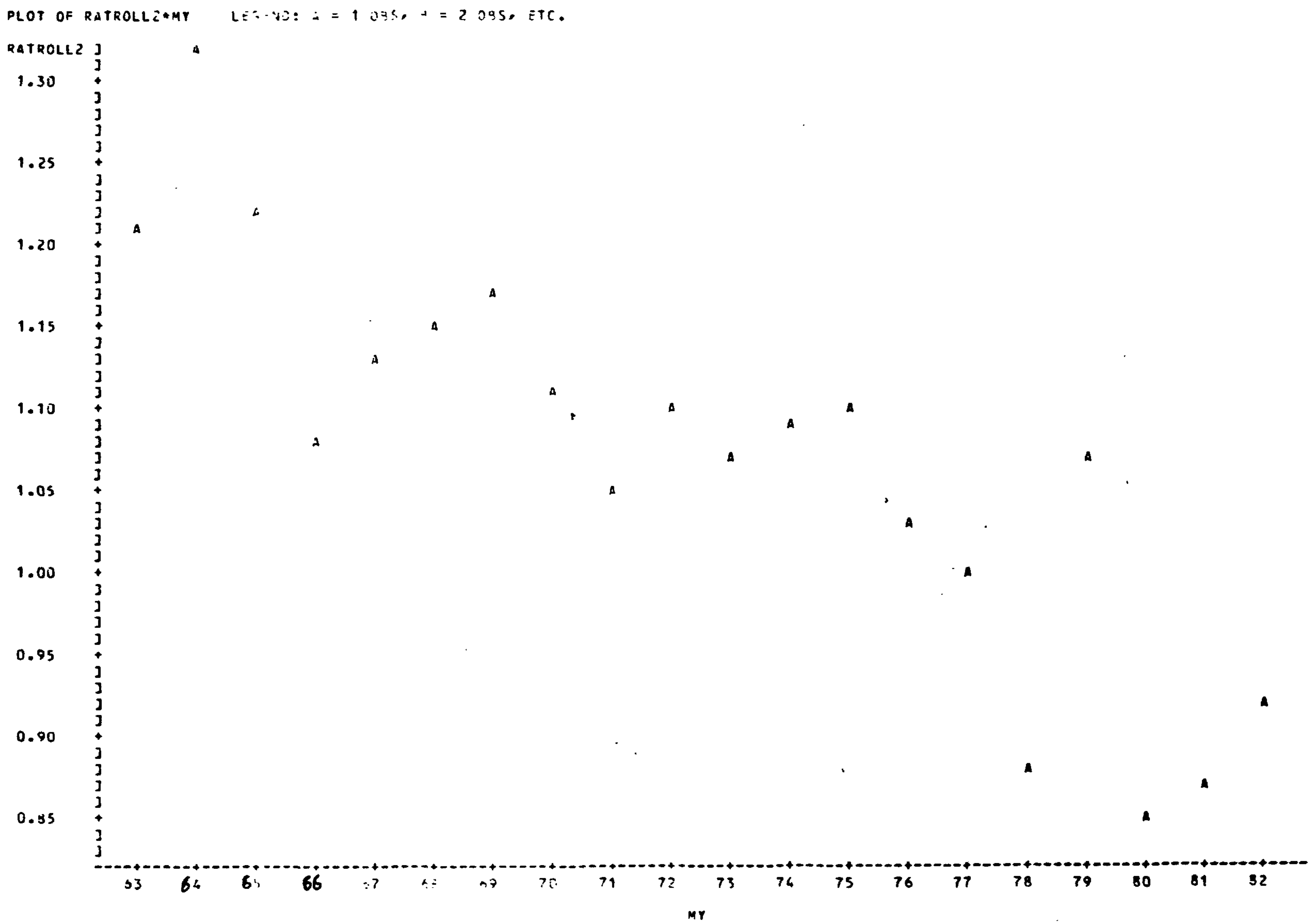
7.1 Analysis objectives and approach

As in Chapter 6, the ultimate objective is to track the intrinsic trend of crashworthiness in rollovers for cars of model years 1963 to 1982. The starting points for the analysis are the trend lines of rollover fatalities relative to fixed object frontal fatalities, based on FARS data (Figures 6-3, 6-4 and 6-5) and the trend lines of rollovers to fixed object frontal crashes, based on Texas data (Figures 5-2A and 5-2B). They are the trend lines for the FARS-based variables LOGROLL, LOGR206, LOGR216 (corresponding to overall, ejection, and nonejection fatality risk) and the Texas-based variables LOGR2 and LOGR3 (two measures of overall rollover propensity). The variables have not been adjusted for track width, curb weight, etc. and they reflect trends in rollover propensity (all 5 variables) as well as crashworthiness (the FARS variables). On the other hand, the effects of driver, roadway and data reporting factors have already been filtered out of these trend lines by the use of frontal fixed object impacts as a control group and by appropriate calendar year corrections to the data (see Sections 5.2 and 6.2). Theoretically, the FARS trend lines measure rollover fatality risk per unit of exposure and the Texas trend lines, rollover risk per unit of exposure.

At first glance, it would be reasonable to divide the FARS rate by the Texas rate to obtain an indicator of rollover fatalities per 100 rollovers - or, more properly, since the variables in these figures are log odds ratios, the Texas variables would be subtracted from the FARS variables. Figure 7-1, for example, is a graph of LOGROLL - LOGR2. It measures the trend in overall fatalities per 100 rollovers. There are impressive reductions in the dependent variable after 1975, coinciding with the market shift to smaller cars. The dependent variable drops from 1.10 to about 0.85, corresponding to a 1 - exp(0.85 - 1.10) = 22 percent reduction in fatality risk per 100 rollovers.

On closer examination, the trend in "fatalities per 100 rollovers" is not a meaningful indicator of crashworthiness. As mentioned in Section 6.4, smaller or less stable cars can roll over in crashes of lower

FIGURE 7-1: LOGROLL - LOGR2 by Model Year (Resembles "Fatalities per 100 Rollovers")



severity than large cars. For example, a small car might roll over if it enters a ditch at 20 mph, where occupant contacts with the interior or stresses to doors and windows might not be severe enough to cause serious injury or ejection. But a large car might not roll over until it enters the same ditch at 30 mph, where risk of injury or ejection is much higher. Since the rollover crashes of small cars are less severe, the fatality risk per 100 rollovers is lower, even though the fatality risk per 100 car years or other unit of exposure is higher. Thus, the improvement after 1975 in Figure 7-1 is primarily associated with car size rather than any genuine crashworthiness improvement.

Since "fatalities per 100 crashes" is so commonly thought of as the best measure of crashworthiness, perhaps one more example is needed to illustrate it is not always so. Consider a State where accidents are reported only if they are fatal or result in over $5000 damage. There, the reported fatalities per 100 crashes of valuable cars such as new luxury sports cars will be moderate, because such cars have many nonfatal crashes with over $5000 damage. But 8 year old full sized sedans will have a very high fatality rate per 100 reported crashes: since they are generally worth less than $5000, hardly any nonfatal crashes would have to be reported. Yet, obviously, that does not prove sports cars are safer than full sized sedans. The same logic pertains to rollovers: large cars have fewer low severity rollovers because they tend not to roll over when the crash dynamics are not severe.

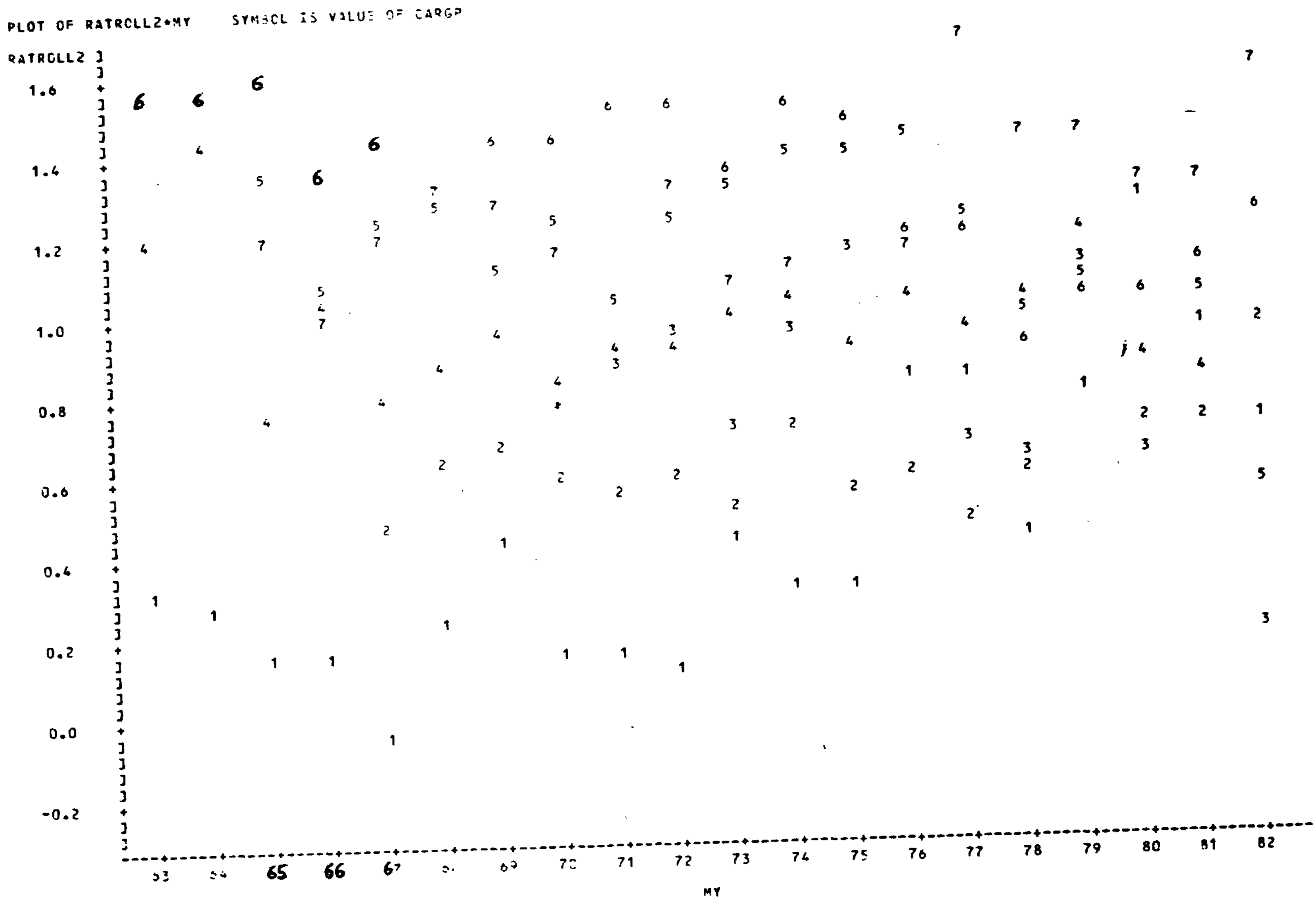
The problem with "fatalities per 100 rollovers" is readily seen if the dependent variable is separately graphed for the seven market classes of passenger cars defined in Chapters 5 and 6:

1. Volkswagens
2. All imports other than Volkswagens
3. Domestic subcompacts
4. Domestic compacts
5. Domestic intermediates
6. Large domestic cars
7. Sporty domestic cars

Figure 7-2 is a graph of LOGROLL - LOGR2 by market class. The pattern is quite consistent: large cars (class 6) consistently had the highest or one of the highest fatality rates per 100 rollovers, followed by intermediates (5) and compacts (4). Volkswagens (1) consistently had the lowest rates, followed by other imported cars (2). The pattern is the reverse of the one for rollover fatalities per unit of exposure (Figures 6-6 and 6-7) as well as the one for rollovers per unit of exposure (Figure 5-3A). Clearly, LOGROLL - LOGR2 is not a meaningful measure of intrinsic crashworthiness, since it is just as confounded with car size (although in the opposite direction) as LOGROLL itself.

The objective, then, is to seek a measure of crashworthiness that is not confounded with car size - i.e., in which the graph by market class scrambles the classes as much as possible. In Chapter 6, the goal was achieved by adjusting the variables LOGR206 and LOGR216 for vehicle factors such as track width, curb weight, etc. That has the advantage of an intuitive <u>physical</u> explanation for the adjustment process. The disadvantage was that it adjusted <u>only</u> for the specific vehicle factors used in the regression equations - and not for other vehicle factors (such as those which made pre-1969 Volkswagens exceptionally rollover prone) or

FIGURE 7-2: LOGROLL - LOGR2 by Model Year and Market Class
(Resembles "Fatalities per 100 Rollovers")



NOTE: 1J OBS HIDDEN

exposure factors not adequately filtered out by using frontal fixed object impacts as a control group.

Here, the approach is to seek mathematical (specifically, linear) combinations of the variables LOGROLL, LOGR206, LOGR216 with LOGR2 or LOGR3 which cause the greatest scrambling of the results by market class. If the dependent variable has little or no correlation with market class, that, by itself, will be accepted as evidence that the dependent variable measures the crashworthiness trend and that factors affecting rollover proneness have been filtered out. These dependent variables will look like LOGROLL - C x LOGR2 and thus at least mathematically resemble the traditional measure of "casualties per 100 crashes."

7.2 Measuring and maximizing "scrambling" of the market classes

Inspection of graphs such as LOGR2 (Figure 5-3A) or LOGR206 (Figure 6-6) by model year and market class show a rather consistent descending order for classes 1-6, year after year. Classes 1-6 have also had a consistent rank order in car size and weight: e.g., even though large and intermediate cars have grown and shrunk over the years, in any given model year the large cars are wider and heavier than the intermediates. Class 7 (sporty domestic cars), on the other hand, do not fit in that order and have moved up and down in the ranks over the years. Thus, the analysis is limited to measuring how well classes 1-6 are scrambled.

The graphs of LOGR2, LOGR206 and LOGROLL - LOGR2 (Figure 7-1) for market classes 1-6 come close to perfect consistency of the rank ordering from year to year, in either ascending or descending order, as exhibited by the following hypothetical data:

1	1	1	1		6	6	6	6
2	2	2	2		5	5	5	5
3	3	3	3		4	4	4	4
4	4	4	4		3	3	3	3
5	5	5	5		2	2	2	2
6	6	6	6		1	1	1	1
63	64	65	66 ...		63	64	65	66 ...

Both of these arrangements are obviously "not scrambled at all." The key question in measuring the degree of "scramble" in other arrangements is: what kinds of patterns are important to eliminate?

Above all, the new dependent variable must not have consistently high rates for small cars and/or low values for big cars - or vice versa. The more it puts the 1's and 6's in the middle, the better. In any given model year, there should be close to zero rank order correlation between market class and the dependent variable. Rank order correlation can be measured by Spearman rho or Kendall tau. The sum of the <u>squares</u> of the rank order correlations (SSROC) for each of the 20 model years (1963-82) is a measure of consistency across the entire data set and it needs to be minimized. (The correlations need to be squared to prevent positive and negative correlations from cancelling each other out.) Perfectly consistent data, such as either of the arrangements shown above, would get a SSROC of 20. LOGR2, for example, comes close to perfect consistency, receiving a SSROC of 17.67 (using Spearman rho) or 16.04 (using Kendall tau).

SSROC is desirable because it concentrates on the values of the dependent variable for small and large cars, but it does not eliminate all patterns in the data. For example, the arrangement

4	4	4	4	
2	5	2	5	
1	1	1	1	
6	6	6	6	
5	2	5	2	
3	3	3	3	
63	64	65	66	...

would have a low SSROC but it is obviously not "scrambled." There is a definite pattern of class 4 being consistently highest and class 3 lowest. Also classes 1 and 6 are consistently near the middle; in ideally scrambled data they ought to vary randomly around the pack.

The Kendall coefficient of concordance [84], pp. 229-238 is an appropriate statistic for detecting the presence or absence of consistent patterns across model years. Each model year is treated as an independent "judge" that "ranks" the 6 market classes from 1st to 6th in rollover risk, according to the values of the dependent variable for that model year. The arrangement shown just above would have close to a maximum coefficient of concordance because each "judge" ranked class 4 worst, class 3 best, etc. A low coefficient of concordance is evidence that rankings vary chaotically across model years - whereas SSROC considered each model year a separate case and did not care if the pattern was the same for each model year. On the other hand, SSROC has the advantage of emphasizing what the dependent variable does to small and large cars; the coefficient of concordance treats all patterns equally and does not penalize a dependent variable that consistently makes large cars worst any more than one which makes medium size cars worst.

Since the coefficient of concordance and SSROC are both useful measures serving different purposes, both are calculated - and SSROC is calculated using both Spearman rho and Kendall tau. Dependent variables that have low values on all three of the measures are considered the ones that scramble the data most.

A special problem with the Kendall coefficient of concordance as defined in [84], pp. 229-238 is that it assumes a complete data set: a value for every market class in every model year. Rollover rates, however, are not available for some classes in some years - e.g., domestic subcompacts were not built before 1971. The calculation of the coefficient has been modified, as shown below, to allow for cells which are empty by design. Consider the data arrangement:

1	1	1	1
2	2	2	2
		3	3
4	4	4	4
5	5	5	5
6	6	6	6
... 69	70	71	72 ...

Two of the "judges" (model year 69 and model year 70) only had five market classes to "rate." In order to produce "ratings" ranging from 1 to 6, the five market classes are prorated as follows:

Ranks of Market Classes within Model Year

	Model Year	Market Class 1	2	3	4	5	6
	69	1	2.25		3.5	4.75	6
	70	1	2.25		3.5	4.75	6
	71	1	2	3	4	5	6
	72	1	2	3	4	5	6
	Rank Sum	4	8.5	6	15	19.5	24
	Proportion Nonmissing	1	1	0.5	1	1	1
$R_j =$	$\frac{\text{Rank Sum}}{\text{Prop Nonmiss}}$	4	8.5	12	15	19.5	24

The statistics R_j in the last row of the preceding table are used in the same way as the R_j on p. 233 of [84] to calculate the coefficient of concordance (with k = 20 and N = 6 in formula 9.15 on p. 233 of [84]).

An arrangement with perfect agreement in the rank order from year to year would achieve a coefficient of concordance equal to 1. LOGROLL, for example, comes close to perfect concordance, receiving a coefficient of .868.

The next step is to compute the matrix of values, by market class and model year, for LOGROLL - LOGR2/X, where X is a positive number, and to compute the values of the coefficient of concordance and SSROC for that matrix. The computation is repeated for several values of X until the minima of the coefficient of concordance and SSROC are located:

Measures of "Scramble" in LOGROLL - LOGR2/X

		Sum of Squares of Rank Order Correls.	
X	Coeff. of Concordance	Spearman rho	Kendall tau
1	.651	14.82	13.36
1.5	.190	9.87	8.25
1.6	.141		
1.7	.130		
1.75	.118	8.48	6.15
1.8	.122	7.52	5.28
1.9	.128		
1.95		6.19	4.41
2.0	.178	6.30	4.39
2.05		6.27	4.32
2.1		6.31	4.28
2.15		6.23	4.47
2.2		5.91	4.36
2.25	.310	6.01	4.44
2.3		6.09	4.50
2.4		7.40	5.55
infinity	.868	16.18	13.59
X with most scramble:	1.75	2.20	2.10

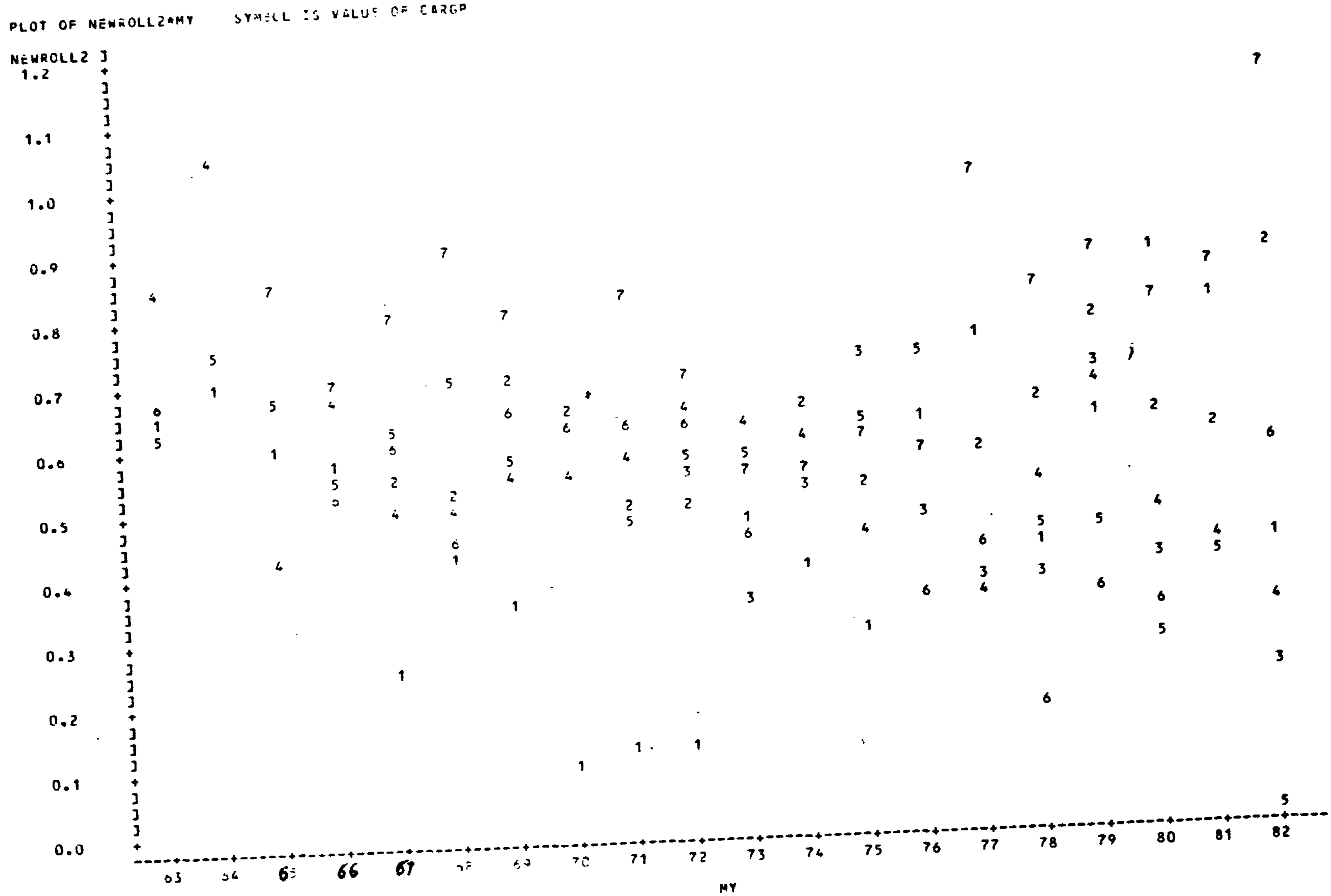
Kendall's coefficient of concordance reaches a minimum value of .118 for the variable LOGROLL - LOGR2/1.75. SSROC, as measured by Spearman rho, reaches a minimum of 5.91 when X = 2.2; as measured by Kendall tau, a minimum of 4.28 is achieved when X = 2.1. All of these statistics stay close to the minimum value within a moderate range of X. The value of X which "best scrambles" the data is somewhere between the minima for the concordance coefficient and SSROC. More weight should be given to the concordance coefficient, as it is a more natural test of patterns in the data. That would suggest X = 1.9 is about the best all around. Define

$$NEWROLL2 = LOGROLL - LOGR2/1.9$$

as the mathematical combination of LOGROLL and LOGR2 which most closely indicates the trend in overall fatality risk in rollovers, after controlling for changes in rollover propensity.

Figure 7-3 is a graph of NEWROLL2 by model year and market class. It is easy to see that market classes 1-6 are well scrambled. None of them consistently occupies any particular position in the pack (low coefficient of concordance). Classes 1 and 6, in particular, do not spend much time at either the top or the bottom of the pack (low SSROC). On the other hand, sporty domestic cars (class 7), which were not included in the calculations of SSROC and the concordance coefficient, have consistently higher than average fatality risk. That is an appropriate result, for they are all 2 door cars and have a higher ejection risk than other market classes, after controlling for rollover propensity.

FIGURE 7-3: NEWROLL2 by Model Year and Market Class
(Fatality risk adjusted for rollover propensity)



NOTE: 14 OBS HIDDEN

A similar procedure is used to study fatal ejections in rollovers. The goal is to find X which minimizes consistency across market classes in functions of the form LOGR206 - LOGR2/X (where LOGR206 is the unadjusted ejection fatality risk in FARS). Kendall's coefficient of concordance reaches a minimum value of .130 when X = 1.45. SSROC reaches its minimum values when X = 1.60, both for Spearman rho (4.26) and Kendall tau (3.23). Define

NEW206 = LOGR206 - LOGR2/1.5

as the mathematical combination of LOGR206 and LOGR2 which most closely indicates the trend in ejection fatality risk in rollovers, after controlling for changes in rollover propensity.

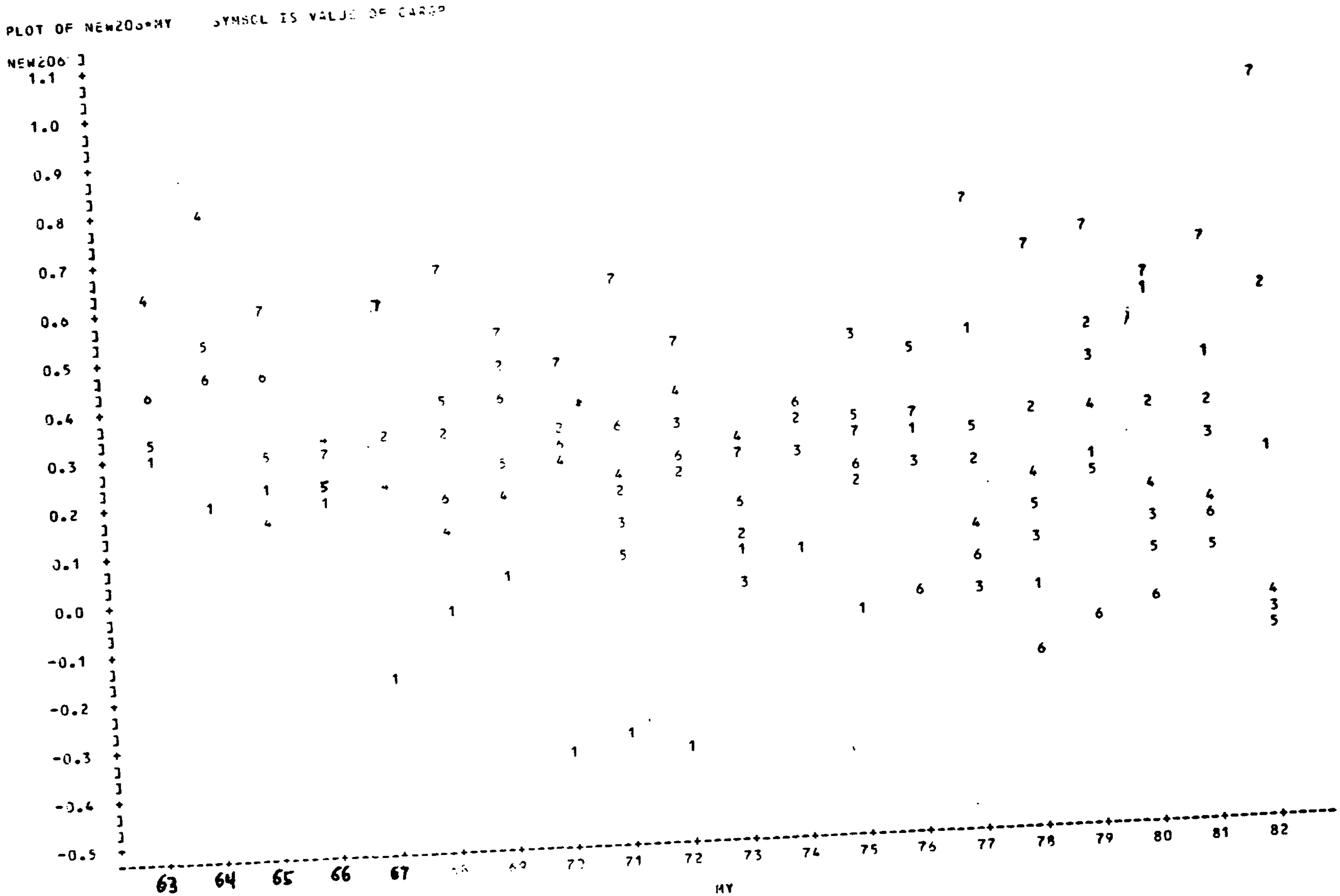
Figure 7-4 is a graph of NEW206 by model year and market class. Market classes 1-6 are usually well scrambled, although there is a period in the late 1960's and early 1970's when Volkswagens (class 1) are on the low side. Sporty domestic cars (class 7) have consistently higher than average ejection risk.

The trend in fatality risk of persons who were not ejected in rollovers will be a function of the form LOGR216 - LOGR2/X. Kendall's coefficient of concordance reaches a remarkably low value of .013 when X = 3.35. SSROC is minimal at X = 3.25, both for Spearman rho (6.36) and Kendall tau (4.43).

NEW216 = LOGR216 - LOGR2/3.3

does the best job of indicating the trend in nonejection fatality risk in rollovers, after controlling for changes in rollover propensity.

FIGURE 7-4: NEW206 by Model Year and Market Class
(Ejection fatality risk adjusted for rollover propensity)



NOTE: 13 OBS HIDDEN

Figure 7-5 is a graph of NEW216 by model year and market class. Market classes 1-6 are almost randomly distributed, as reflected by the very low coefficient of concordance. Sporty domestic cars (class 7) are not consistently above average here: that is appropriate, because their being 2 door cars should not affect the nonejection fatalities.

All of the preceding trend variables were based on LOGR2, a measure of rollover propensity in Texas data where the calendar correction included a vehicle age effect. In Section 5.2, another variable LOGR3 was defined without a vehicle age effect in the calendar year correction. Throughout Chapter 5, each analysis was performed using LOGR2 and LOGR3. Here, too, it is possible to define the crashworthiness trend variables using LOGR3 instead of LOGR2. An examination of Figures 5-3A and 5-3B shows that LOGR2 and LOGR3 have virtually identical rank orderings of the market classes <u>within</u> any given model year. Since SSROC and the coefficient of concordance are both calculated by looking at rank orderings of the market classes within model year, the values of X that most scrambled the functions of LOGR2 should work equally well for functions of LOGR3. Define

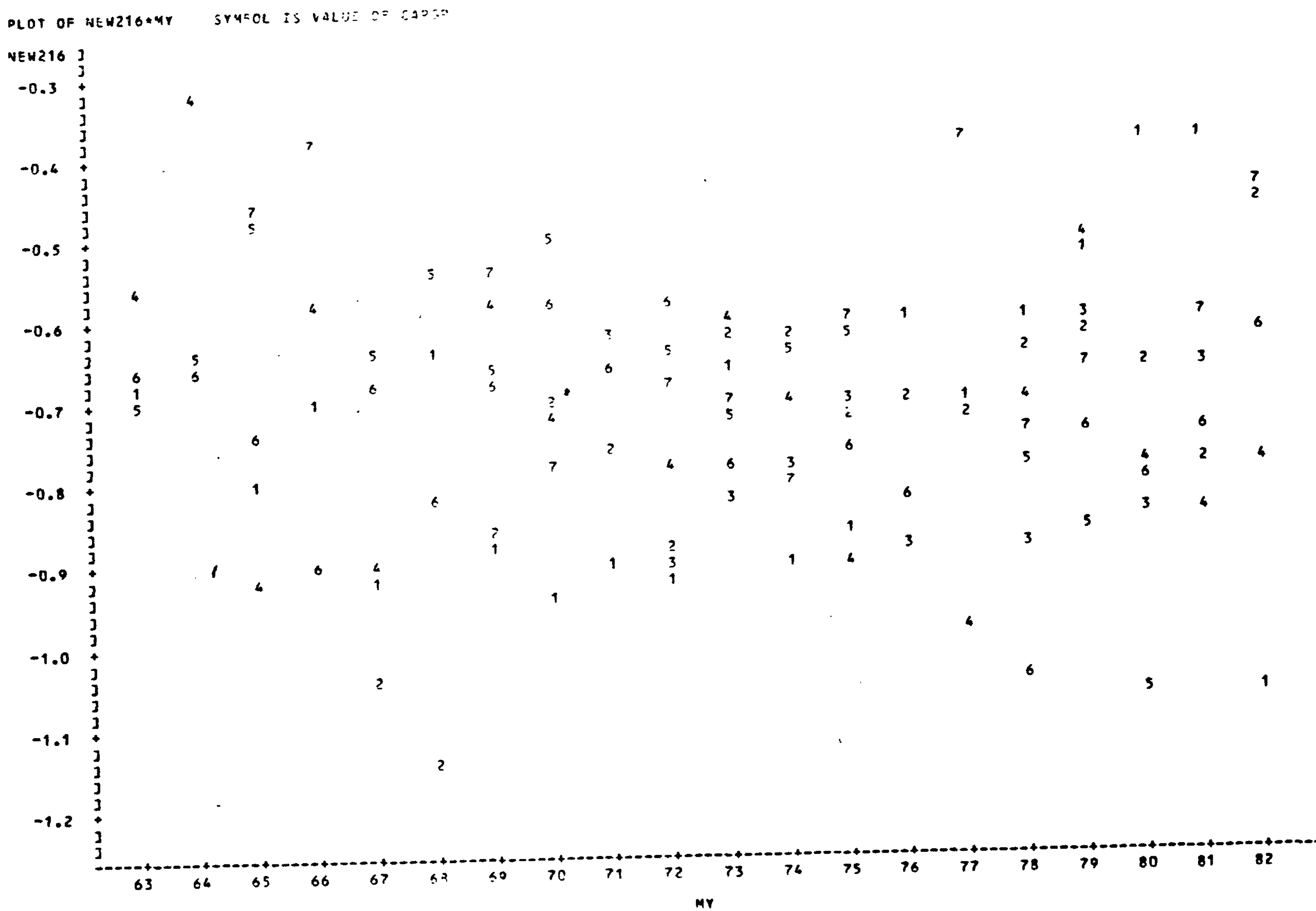
$$NEWROLL3 = LOGROLL - LOGR3/1.9$$

$$NEW306 = LOGR206 - LOGR3/1.5$$

$$NEW316 = LOGR216 - LOGR3/3.3$$

as the linear functions of LOGR3 which best measure the overall, ejection and nonejection fatality trends in rollovers, after controlling for rollover proneness.

FIGURE 7-5: NEW216 by Model Year and Market Class
(Nonejection fatality risk adjusted for rollover propensity)



NOTE: 17 OBS HIDDEN

7.3 Crashworthiness trend lines

The last step of the modeling process is to aggregate the data across market classes and obtain an estimate of the average intrinsic crashworthiness by model year. Figures 7-6A and 7-6B present the trends for ejection fatality risk; Figure 7-6A is a graph of NEW206 and Figure 7-6B, NEW306. Both figures show a substantial reduction in the risk of ejection during the mid 1960's, with a possible additional reduction in the late 1960's. From model year 1970 to 1982, differences seem to be in the noise range (and there is more noise after 1977 or so, as the accident data samples get steadily smaller). In Figure 7-6A, NEW206 averages about .47 in model years 1963-64 and about .27 from model year 1970 onwards, corresponding to a 1 - exp(.27 - .47) = 18 percent reduction in ejection fatality risk, after controlling for changes in rollover propensity. In Figure 7-6B, NEW306 averages about .58 in model years 1963-64 and about .30 from model year 1970 onwards, corresponding to a 24 percent reduction in ejection fatality risk.

These are higher estimates than the 10 percent found for domestic cars in Section 6.5. That is primarily because these estimates include Volkswagens (which had to be excluded in Chapter 6 for the analysis to work). Volkswagens accounted for about 20 percent of rollover ejection fatalities in cars of the mid 1960's, according to the FARS data. Thus, a large reduction in Volkswagens could pull the average for all cars up quite a bit. They received major door lock improvements in the later 1960's [11], [32]. Door locks of domestic cars were also improved at that time, but those were just increments in a process of door

FIGURE 7-6A: NEW206 by Model Year (Ejection fatality risk adjusted for rollover propensity - Texas calendar year correction <u>including</u> vehicle age term)

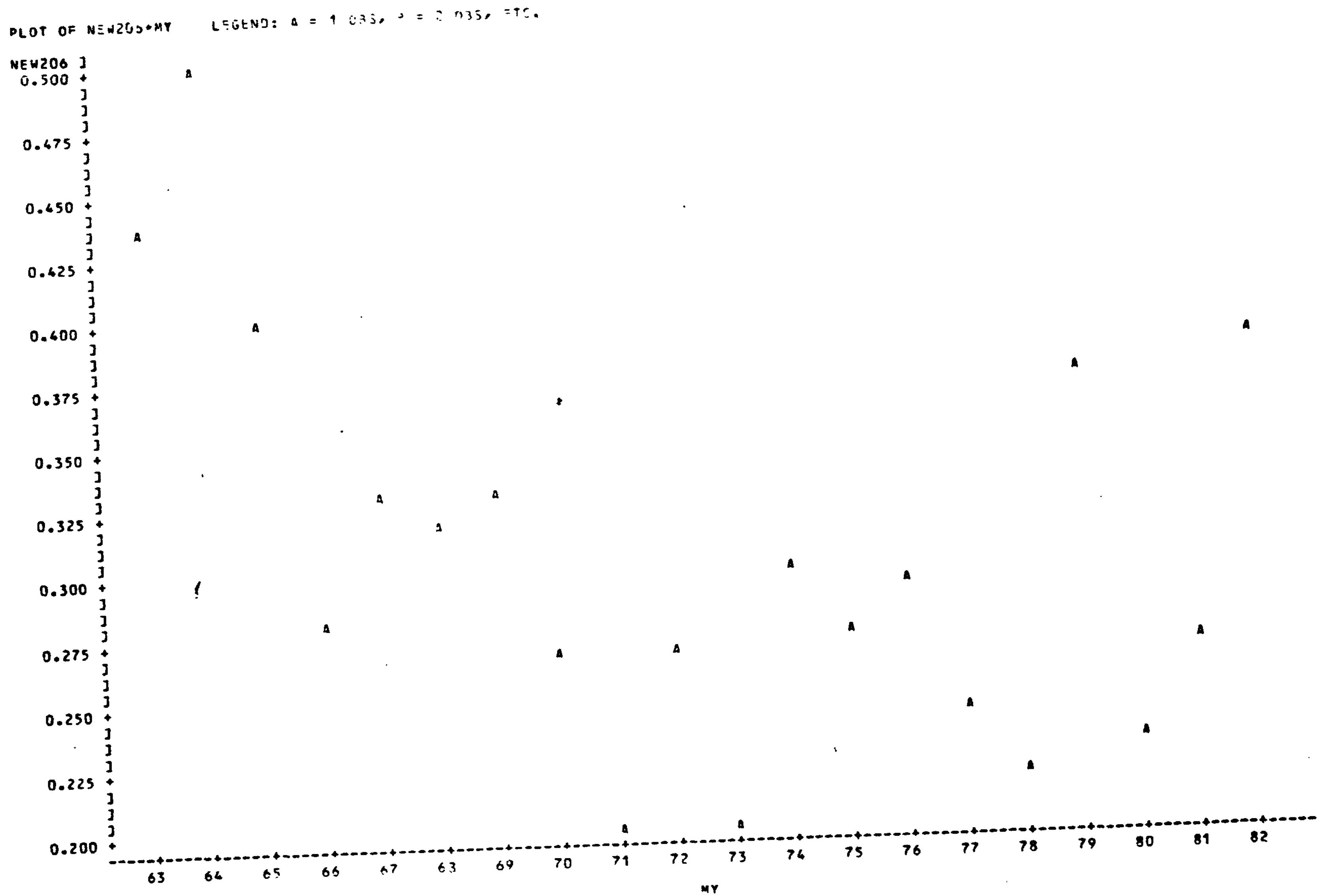
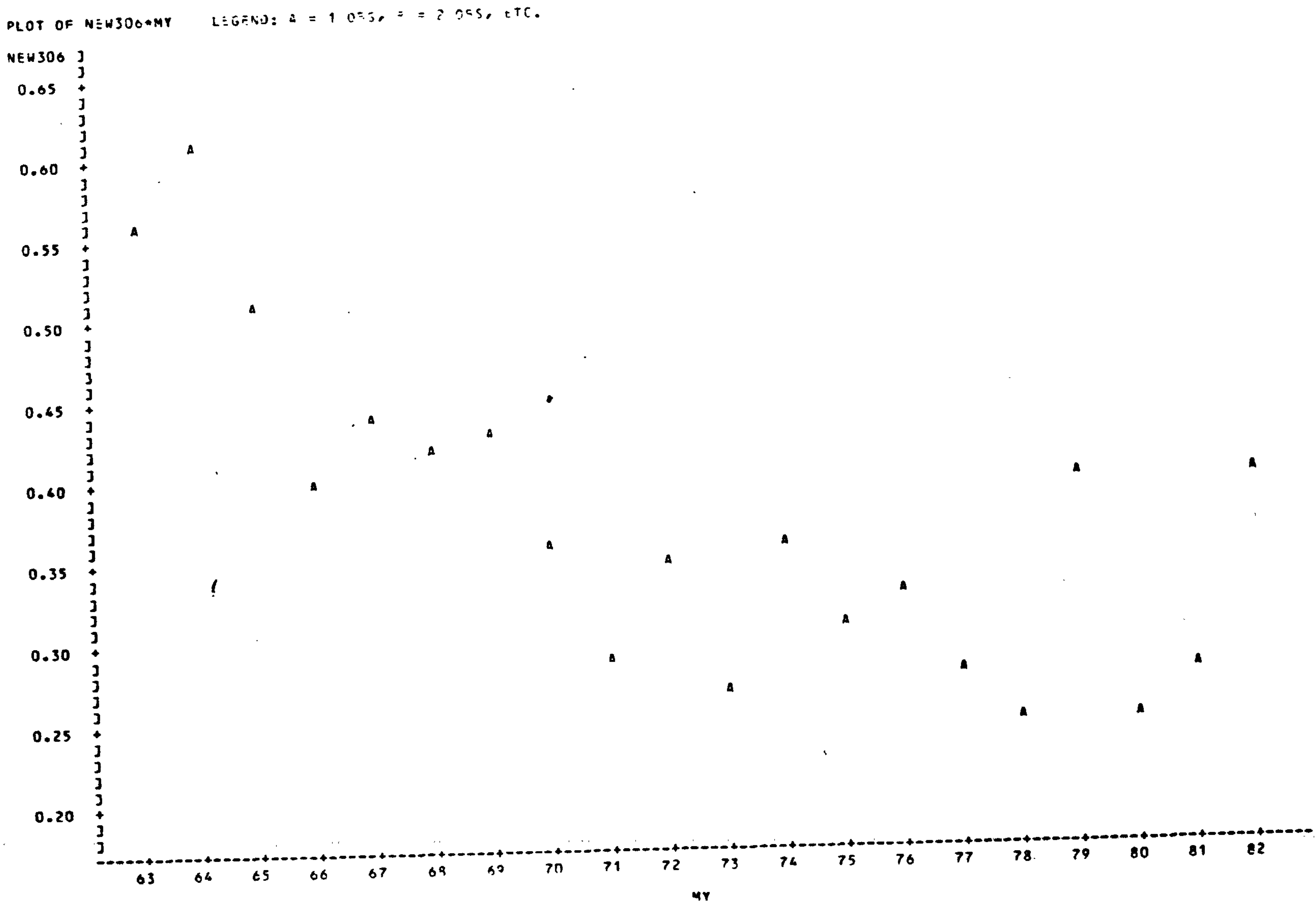


FIGURE 7-6B: **NEW306 by Model Year (Ejection fatality risk adjusted for rollover propensity – Texas calendar year correction <u>excluding</u> vehicle age term)**



lock improvements stretching back to 1956 [30], [31]. As a result, the fatality reduction in Volkswagens was, relatively speaking, larger than in domestic cars.

Figures 7-7A and 7-7B depict the intrinsic fatality risk of persons who were <u>not ejected</u>; Figure 7-7A is a graph of NEW216 and Figure 7-7B, NEW316. Both figures suggest there was some reduction during the 1963-82 period, but it is not so easy to place the timing of the reduction because of the noise in the data. A glance at the vertical axis shows that the points vary within a range of just ±9 percent or less: it's not that there is so much noise, rather there is so little signal. These data, by themselves, do not allow definitive conclusions about the magnitude and timing of the fatality reduction, but at least they show enough of a pattern to support the conclusions of Chapters 3, 4 and 6. Fatality risk appears to be fairly steady during model years 1963-71; it drops during 1972-75, the years during which true hardtops were changed to pillared hardtops or were strengthened to meet Standard 216; it reaches a lower plateau after model year 1975. According to Figure 7-7A, NEW216 averaged about -.67 up to model year 1971 and about -.72 from model year 1975 onwards, corresponding to a 5 percent reduction in the fatality risk of persons who were not ejected. According to Figure 7-7B, NEW316 averaged about -.62 up to model year 1971 and about -.72 from model year 1975 onwards, corresponding to a 10 percent reduction in fatality risk.

The effectiveness range of 5 to 10 percent corresponds closely to the estimate of 8 percent obtained in Section 6.6. Here, unlike the

FIGURE 7-7A: NEW216 by Model Year (Nonejection fatality risk adjusted for rollover propensity - Texas calendar year correction including vehicle age term)

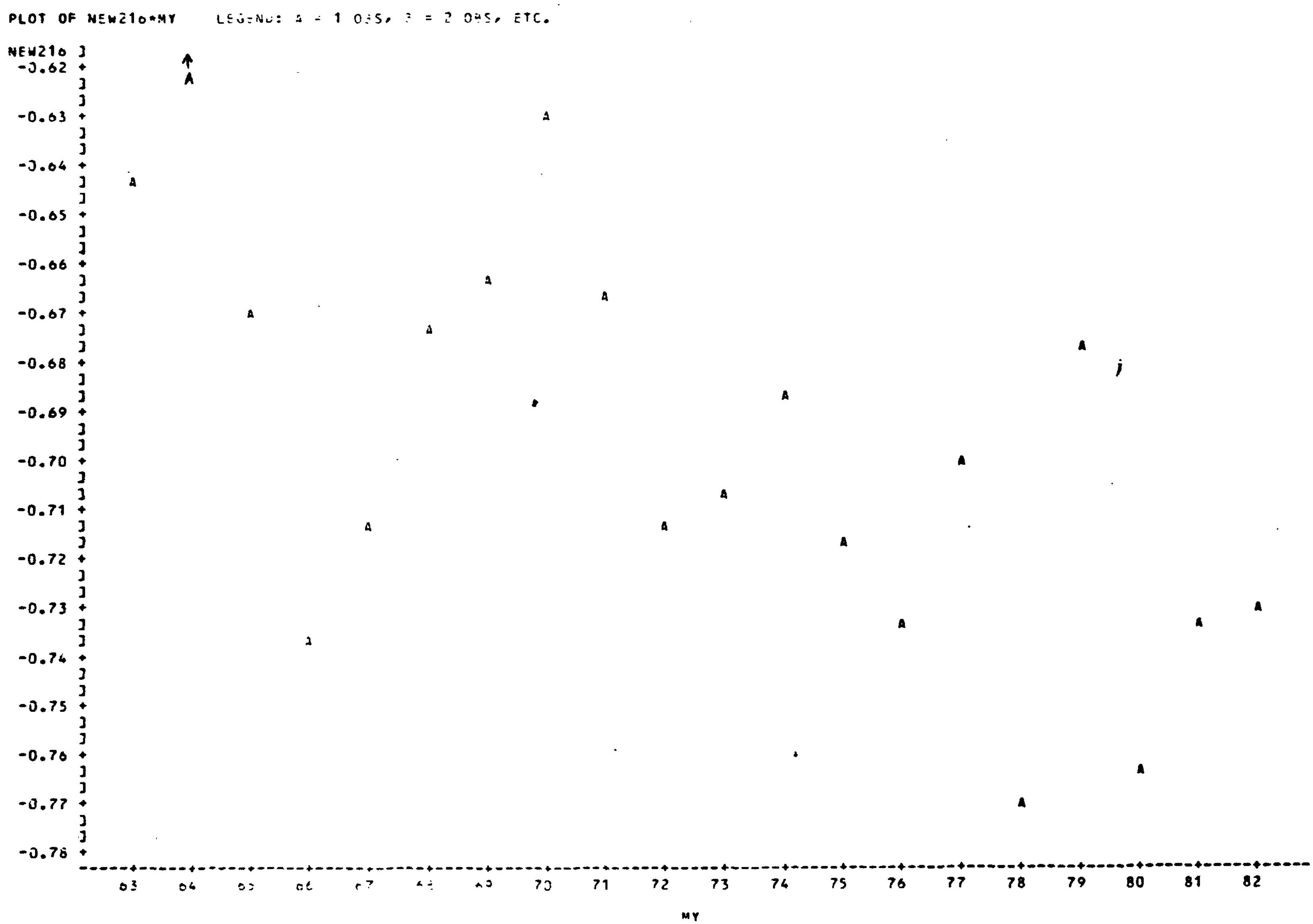
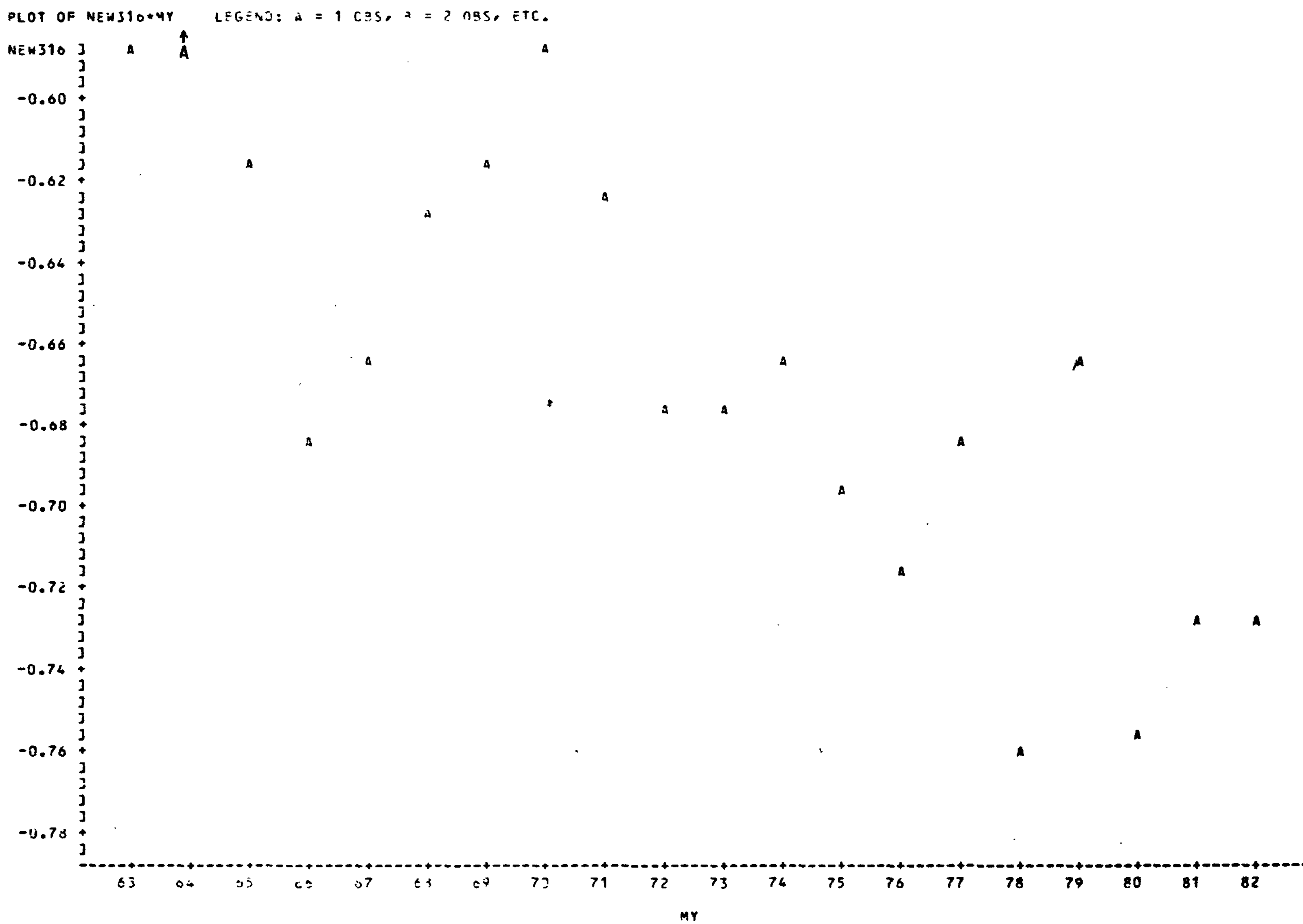


FIGURE 7-7B: NEW316 by Model Year (Nonejection fatality risk adjusted for rollover propensity - Texas calendar year correction <u>excluding</u> vehicle age term)



analysis for ejections, the method of Chapter 6 seems to work better. In Section 6.6, it was possible to analyze sedans and hardtops separately, but hardtops and sedans cannot be distinguished in the Texas data used here. Also, the trend line in Figure 6-13 has less noise in it than the trend lines in Figures 7-7A and 7-7B.

The overall crashworthiness trend in rollovers (ejections and nonejections combined) is illustrated by Figures 7-8A and 7-8B. Figure 7-8A is a graph of NEWROLL2 and Figure 7-8B, NEWROLL3. Figure 7-8A shows a clear reduction in fatality risk during the mid and later 1960's, coinciding with the implementation of improved door locks. After model year 1970, there are no obvious changes. The effects of the change from true to pillared hardtops are not clearly visible. NEWROLL2 is based on NEW216 and NEW206; Figure 7-7A showed only a 5 percent reduction in NEW216 during the mid 1970's. A 5 percent reduction of nonejection fatalities is equivalent to a 2 percent reduction of all rollover fatalities - a change that is lost in the "noise." Figure 7-8A shows that NEWROLL2 decreased from about .73 in model years 1963-64 to about .58 in model years 1975-82. That corresponds to a 1 - exp(.58 - .73) = 14 percent fatality reduction.

Figure 7-8B shows that NEWROLL3 dropped significantly during the mid 1960's and continued to fall at a slower rate in cars of the late 1960's and early 1970's, leveling out after model year 1975. The effects of the change from true to pillared hardtops are just barely visible: the 10 percent reduction of NEW316 during the mid 1970's is equivalent to a 4

FIGURE 7-8A: NEWROLL2 by Model Year (Overall fatality risk adjusted for rollover propensity - Texas calendar year correction <u>including</u> vehicle age term)

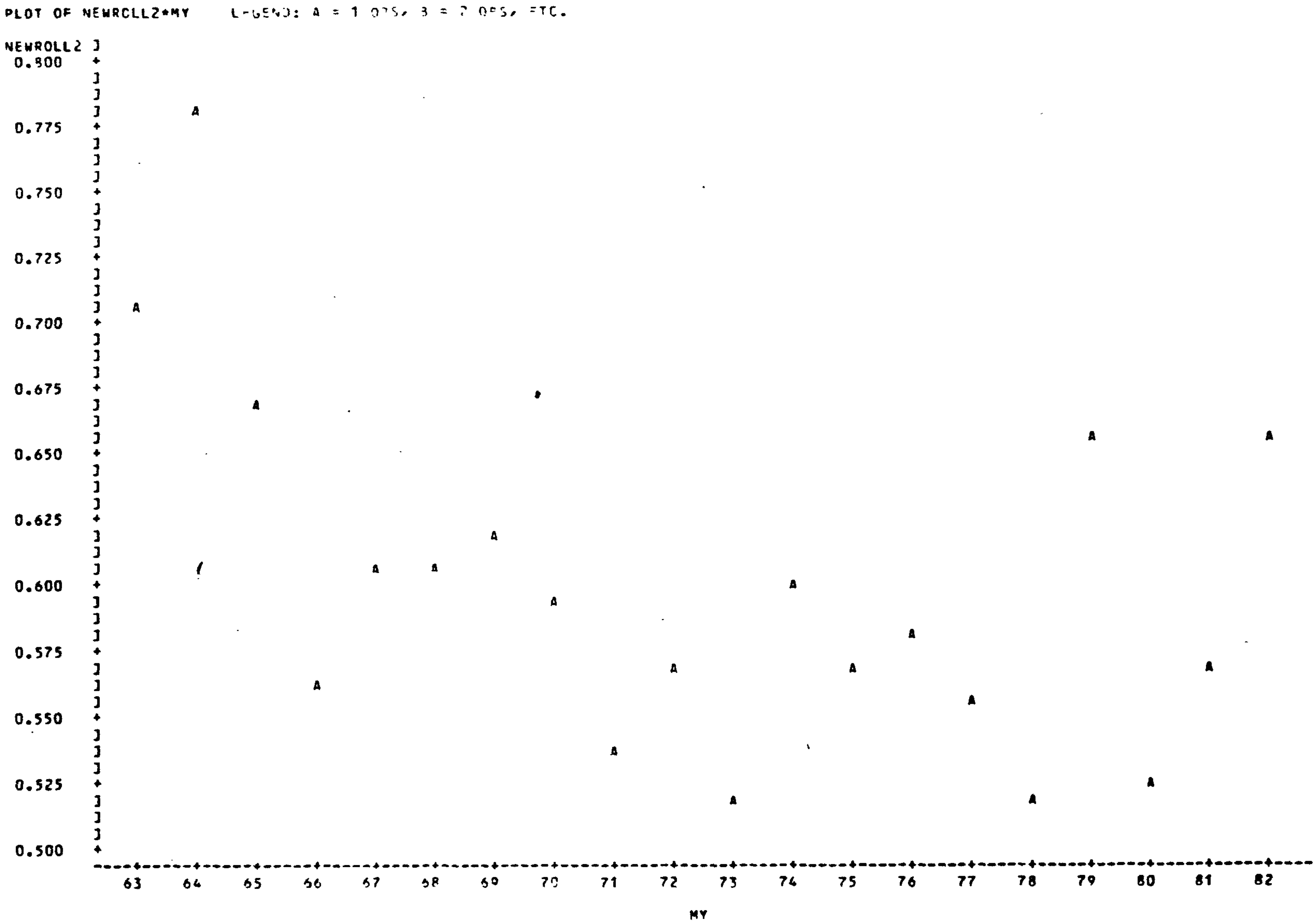
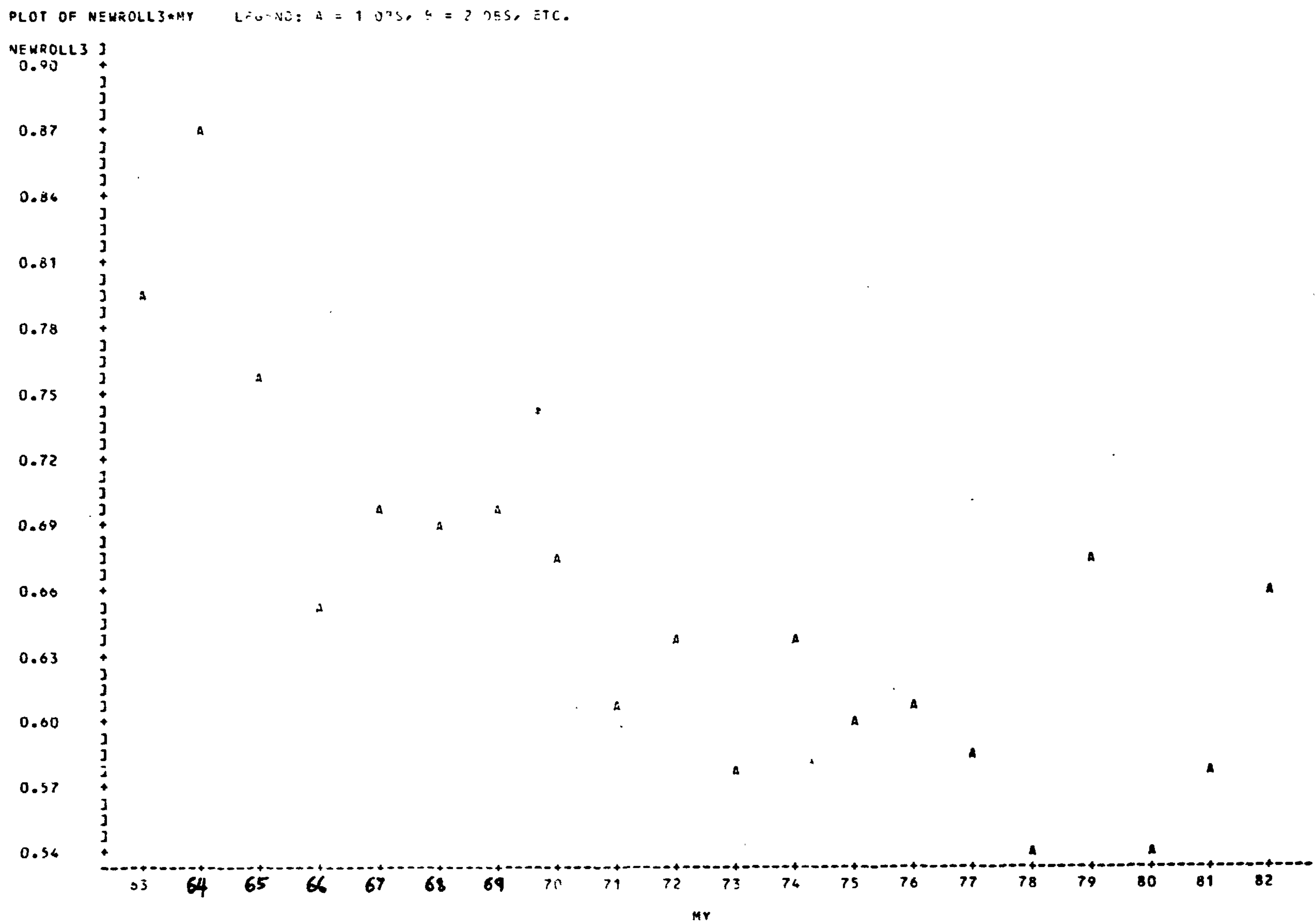


FIGURE 7-8B: NEWROLL3 by Model Year (Overall fatality risk adjusted for rollover propensity - Texas calendar year correction <u>excluding</u> vehicle age term)



percent reduction of all rollover fatalities. Figure 7-8B shows that NEWROLL3 decreased from about .82 in model years 1963-64 to about .61 in model years 1975-82, corresponding to a 19 percent fatality reduction.

7.4 Rollover crashworthiness indices

The results of the preceding Sections 6.6 and 7.3 can be used to generate rollover crashworthiness indices for the entire passenger car fleet, by model year, analogous to the frontal crashworthiness indices defined in NHTSA's evaluation of occupant protection in interior impact [47] and also to the rollover propensity indices defined in Section 5.6. A crashworthiness index can be generated for ejectees, for nonejectees and for overall fatality risk in rollovers.

In the preceding section, LOGR206, NEW206 and NEW306 represented the logarithm of the odds ratio of rollover ejection fatalities to fixed object impact fatalities, with or without adjustment for rollover propensity. Let LOGR206(75-80) be the average of the values of LOGR206 for model years 1975 through 1980. For any model year MY, the index is set equal to 100 exp[LOGR206(MY)]/exp[LOGR206(75-80)]. In other words, the index averages close to 100 for the baseline model years 1975-80 and is higher than 100 in model years where LOGR206 is higher than the average for the baseline years. The procedure is similar for NEW206 and NEW306. If the index is 100 in one model year and 90 in the next, it means that ejection fatality risk decreased by 10 percent (with or without adjustment for car size and weight, depending on which variable is used to calculate the index).

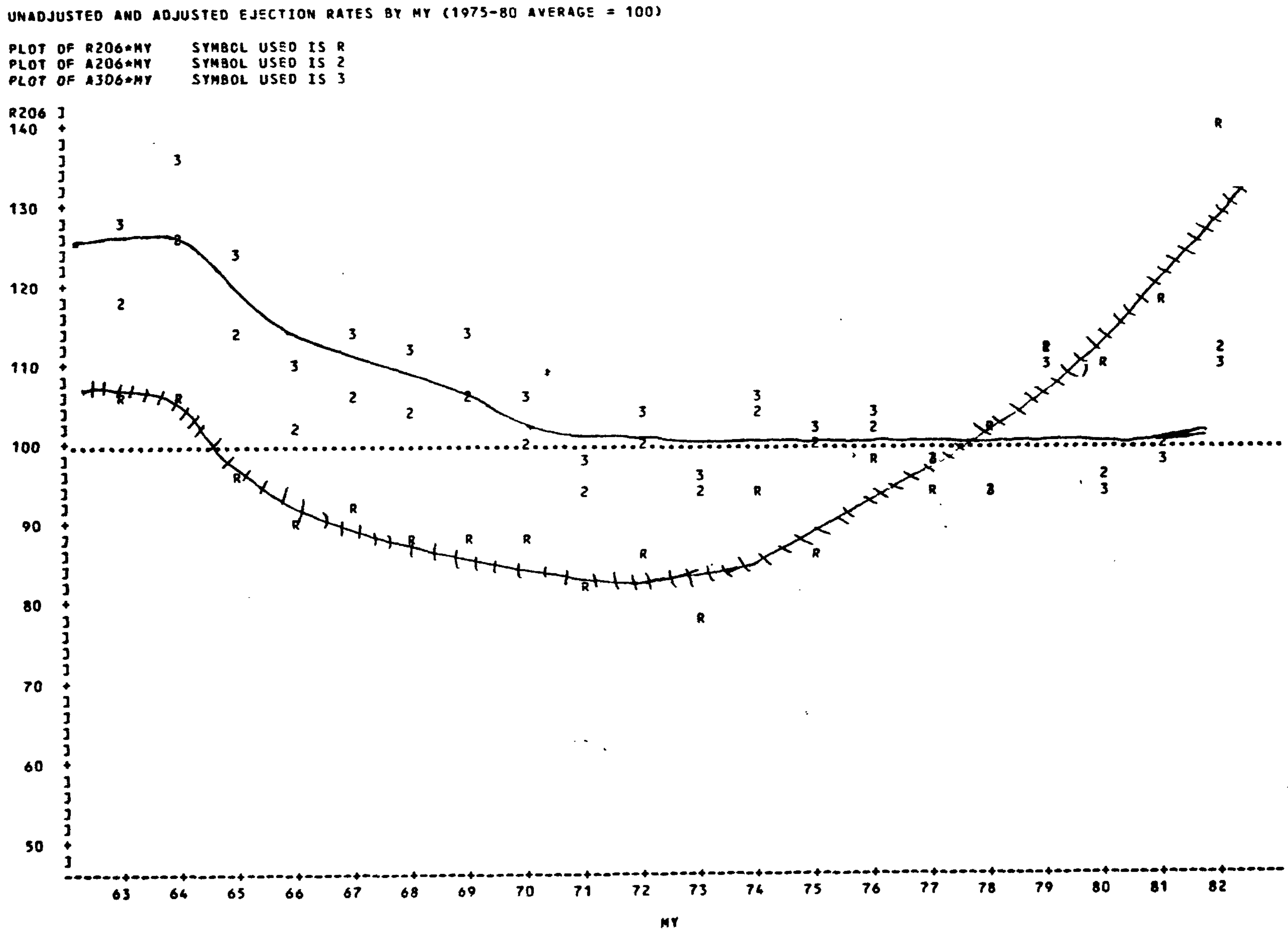
The values of the indices are:

Model Year	Index Based On LOGR206	NEW206	NEW306
1963	105	118	129
1964	106	125	136
1965	95	113	123
1966	89	101	110
1967	93	106	115
1968	88	105	113
1969	88	106	114
1970	87	99	106
1971	82	93	99
1972	85	99	105
1973	78	93	97
1974	93	103	105
1975	86	100	101
1976	97	102	103
1977	94	97	97
1978	103	95	94
1979	112	111	110
1980	110	96	95
1981	118	100	98
1982	141	113	110

Figure 7-9 graphs the indices based on LOGR206, NEW206 and NEW306. The unadjusted index based on LOGR206 is shown as "R" on the figure and is traced by the hatched line. The adjusted indices based on NEW206 and NEW306 are shown as "2" and "3," respectively. The plain line on the graph traces midway between the 2's and the 3's, sometimes smoothing around outlying points. It represents a best estimate for the adjusted ejection index.

The unadjusted ejection index drops during the 1960's, as door locks were improved, reaching its low point in cars of the early 1970's. It rises steadily thereafter as the market shifted to smaller cars; there are more rollovers, therefore more fatal ejections.

FIGURE 7-9: ROLLOVER EJECTION FATALITY INDEX BY MODEL YEAR:
Adjusted for Rollover Propensity = Plain Line
Unadjusted = Hatched Line



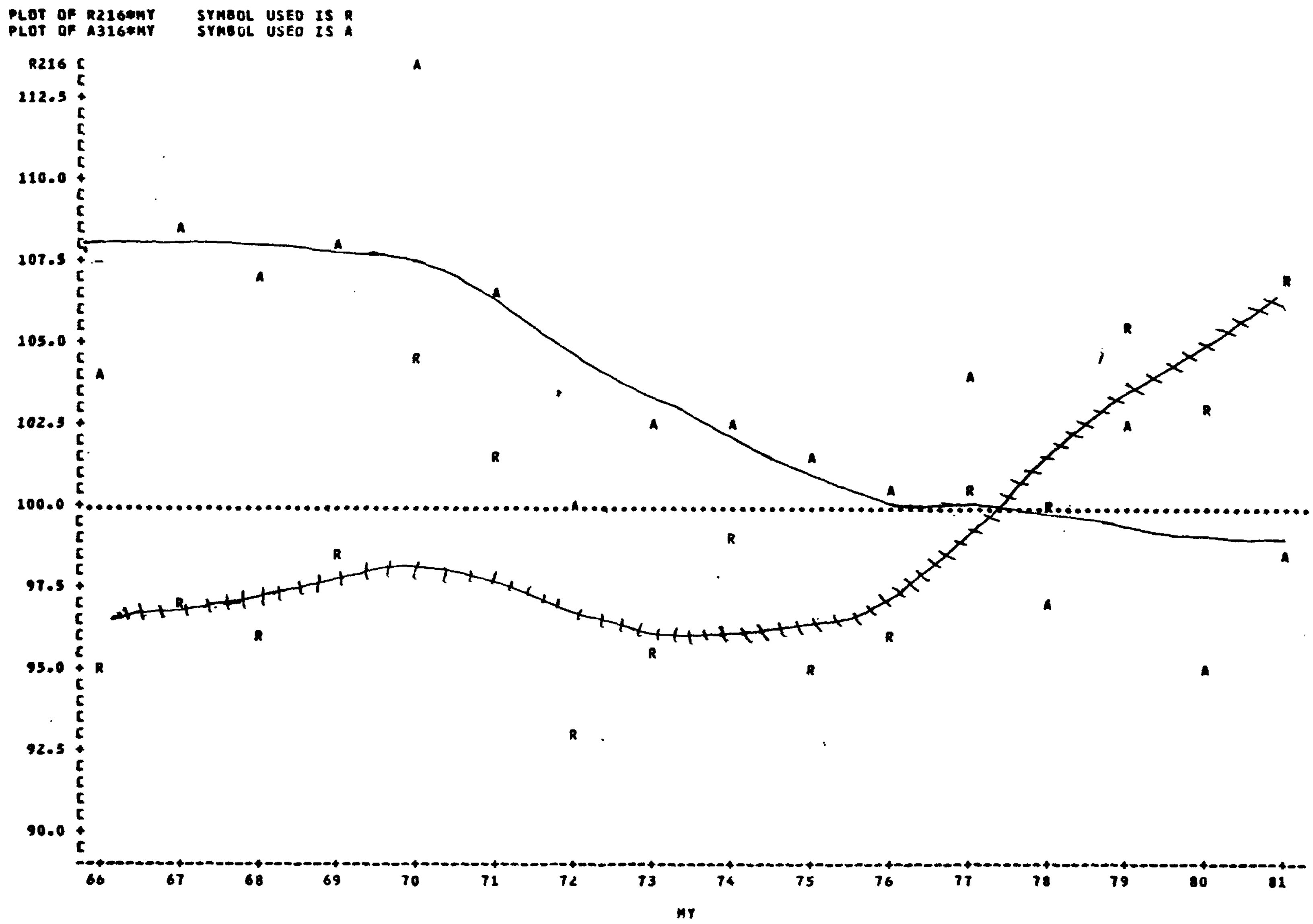
The adjusted index starts in the mid 120's in model years 1963-64, drops to 110 in the mid 1960's and to 100 by model year 1971. It remains close to 100 in all subsequent model years.

The most reliable indicator of <u>nonejection</u> fatality risk, adjusted for rollover propensity, is ADJ316, which was defined in Section 6.6. LOGR216 is the unadjusted risk. The values of the indices based on LOGR216 and ADJ316 are:

	Index Based On	
Model Year	LOGR216	ADJ316
1966	95	104
1967	97	109
1968	96	107
1969	99	108
1970	105	114
1971	101	106
1972	93	100
1973	96	103
1974	99	102
1975	95	101
1976	96	100
1977	101	104
1978	100	97
1979	105	103
1980	103	95
1981	107	98

Figure 7-10 graphs the indices based on LOGR216 and ADJ316. The unadjusted index based on LOGR216 is shown as "R" on the figure and is traced by the hatched line. The adjusted index based on ADJ316 is shown as "A" and is traced by the plain line. The unadjusted index stays close to 100 until model year 1978, but rises during 1979-81 as cars are downsized. The adjusted index is close to 108 until model year 1971. During model years 1972-76, as true hardtops were strengthened or changed to pillared hardtops, the index drops to 100 and it stays close to 100

FIGURE 7-10: ROLLOVER NONEJECTION FATALITY INDEX BY MODEL YEAR:
Adjusted for Rollover Propensity = Plain Line
Unadjusted = Hatched Line



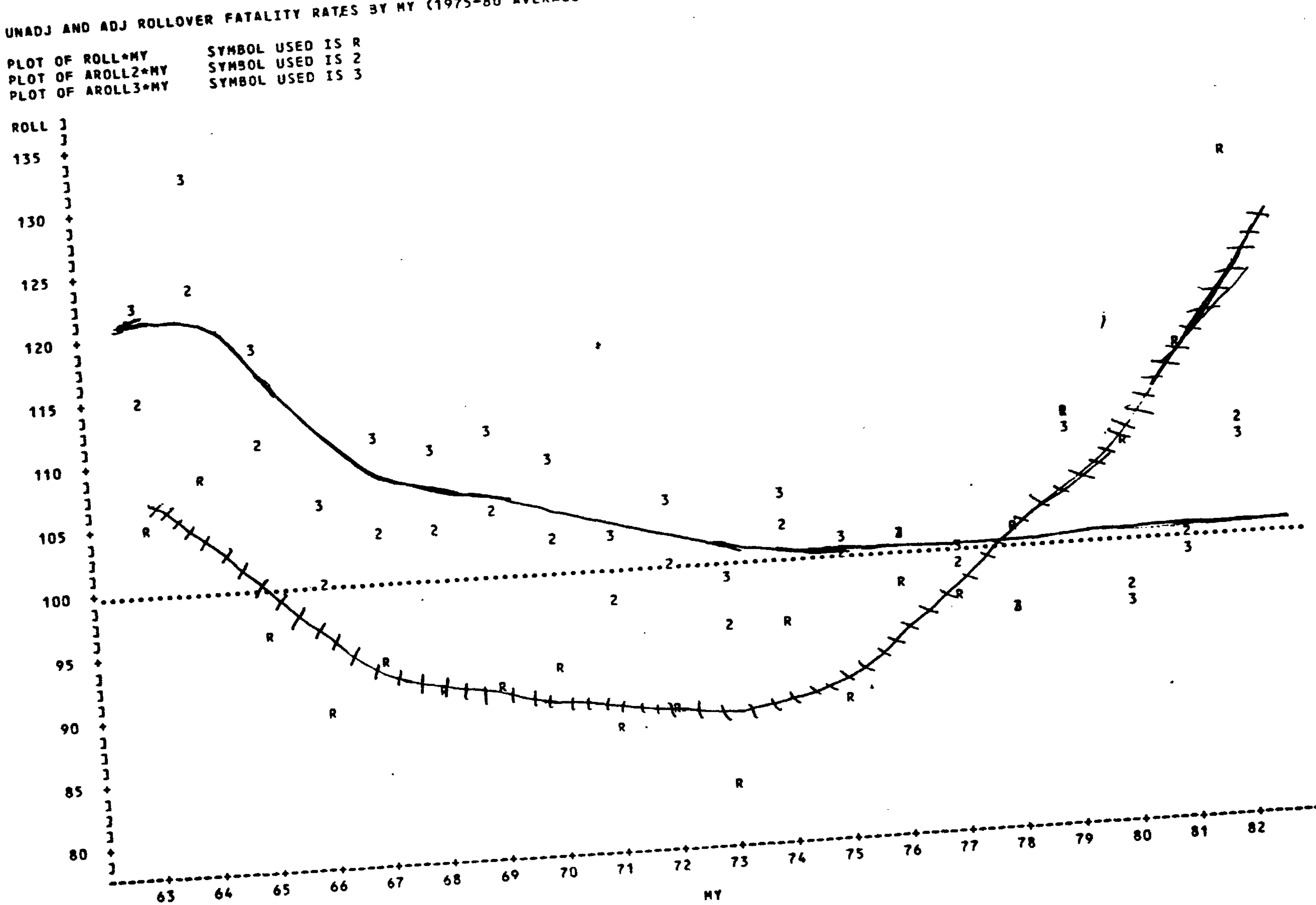
thereafter.

The best indicators of <u>overall</u> fatality risk are LOGROLL, NEWROLL2 and NEWROLL3, defined in the preceding section. The values of the indices based on LOGROLL (unadjusted for rollover propensity), NEWROLL2 (adjusted) and NEWROLL3 (adjusted) are:

Model Year	Index Based On LOGROLL	NEWROLL2	NEWROLL3
1963	105	115	123
1964	108	123	132
1965	97	111	118
1966	90	100	107
1967	93	104	111
1968	91	104	111
1969	91	105	112
1970	93	103	108
1971	88	97	102
1972	89	100	104
1973	83	95	98
1974	95	103	105
1975	88	100	101
1976	97	101	102
1977	97	99	99
1978	101	95	95
1979	111	109	109
1980	107	96	95
1981	115	100	99
1982	130	109	107

Figure 7-11 graphs the indices based on LOGROLL, NEWROLL2 and NEWROLL3. The unadjusted index based on LOGROLL is shown as "R" on the figure and is traced by the hatched line. The adjusted indices based on NEWROLL2 and NEWROLL3 are shown as "2" and "3," respectively. The plain line on the graph traces midway between the 2's and the 3's, with smoothing. It represents a best estimate for the adjusted fatality index.

FIGURE 7-11: OVERALL ROLLOVER FATALITY INDEX BY MODEL YEAR: Adjusted for Rollover Propensity = Plain Line Unadjusted = Hatched Line



Since the majority of rollover fatalities are ejected, the overall fatality index tends to resemble the ejection index more closely than the nonejection index. The unadjusted overall fatality index drops during the 1960's, as door locks were improved, and continues to drop in the early 1970's, as true hardtops were changed to pillared hardtops. It rises steadily after model year 1975, as vehicles are downsized and there are more rollovers, therefore more fatalities.

The adjusted index starts at about 120 in model years 1963-64, drops to about 107 in the mid and later 1960's and down to 100 in the early 1970's. It has been close to 100 since model year 1975.

CHAPTER 8

THE NET EFFECT OF VEHICLE MODIFICATIONS ON ROLLOVER FATALITIES

Door lock improvements associated with Standard 206 and roof support improvements associated with Standard 216 have enhanced safety in rollover crashes. Together, they save about 500 lives per year. But the shift to smaller and narrower cars has been accompanied by an increase in rollover propensity and, as a result, fatality risk. As a result, a passenger car fleet of model year 1982 cars would experience 500 more fatalities per year than a model year 1963 fleet under similar driving conditions.

8.1 Analysis objectives

The analyses of the preceding chapters as well as a review of the literature suggest 9 vehicle modifications during model years 1963-82 which significantly affected fatalities in rollovers, by changing either rollover propensity or crashworthiness. In chronological order, the 9 modifications are:

Vehicle Modification	Date
1. Improved door locks (Standard 206)	1963-69
2. Shift from 4 door to 2 door cars	1963-74
3. Adhesive bonding of the windshield	1963-82
4. Improved suspension for Volkswagen	1967-69
5. Shift to imported or subcompact cars	1970-82
6. Stop production of true hardtops (Std. 216)	1971-77
7. Downsizing of existing car lines	1975-82
8. Shift from 2 door back to 4 door cars	1976-82
9. Wider tracks for some imported cars	1977-82

The objective is to estimate the net effect of each change on the annual number of fatalities. Specifically, consider a "baseline" passenger car fleet having the same size and weight distribution and the same safety equipment as model year 1982 cars. Now consider an identical fleet of cars, except that the 1982 vintage door locks are replaced by 1963 locks. How many additional fatalities would occur per year? Similarly, the effect of "downsizing of existing car lines" is estimated by comparing the baseline fleet to another fleet having the same distribution, by market class, as in model year 1982, but within each market class the cars are still as big as they were in 1974. The use of a consistent baseline makes it easier to compare the benefits of the various changes.

Model year 1982, however, is not used as a baseline for assessing the effect of improved suspensions and door locks for Volkswagens, which are also the only modifications limited to a specific make or model. Volkswagens were a much smaller percentage of the vehicle fleet in 1982 than in the 1960's when the change actually took place. Calculating the benefits based on 1982 Volkswagen sales would greatly understate the actual benefits that motorists derived in the 1960's.

8.2 Calculation of baseline fatalities

The first task is to estimate the number of rollover fatalities that would occur in a typical year if all cars on the road were built with model year 1982 technology and if the entire car fleet had the model year 1982 market mix. Table 8-1 shows the actual reported numbers of rollover fatalities in Fatal Accident Reporting System (FARS) data in each calendar year of FARS from 1975 through 1986. As defined in Section 6.2, a "rollover fatality" is any passenger car occupant, including rear seat occupants, who was killed in a primary rollover crash. A "primary rollover" crash is one in which the first harmful event was an overturn (HARM_EV = 1) or the most harmful event was an overturn (M_HARM = 1) or the principal damage was to the top of the car (IMPACT2 = 13). In other words, "primary rollovers" can include crashes where the rollover was a subsequent event, but only if it was considered the most severe event.

Table 8-1 shows large fluctuations in the reported number of rollover fatalities, from as low as 2446 in calendar year 1975 up to 5053 in 1980. As described in Section 6.2, a lot of the variation is due to inconsistencies in FARS definitions from year to year. For example, in 1975-78, rollovers are underreported because the "most harmful event" variable did not exist on FARS. Starting in calendar year 1982, the number of fatalities stabilizes within a range of 3544-3996. FARS coding has been more consistent in recent years and the nation's driving environment has not changed much since the big drop in the fatality rate in 1982. During 1982-86 the passenger fleet contained a major proportion of cars similar to model year 1982, but it also contained many older, bigger cars that were less prone to rollover. Thus the number of fatalities in those calendar years somewhat understates what would have happened with a fleet of all model year 1982 cars.

To the nearest thousand, the best "baseline" estimate of rollover fatalities is 4000 per year: the number of fatalities if all cars on the road were built with model year 1982 technology and had the model

TABLE 8-1

FARS 1975-86: REPORTED FATALITIES IN PRIMARY ROLLOVERS
BY CALENDAR YEAR, PASSENGER CARS

Calendar Year	Reported Fatalities Ejected	Nonejected	Total
1975	1365	1081	2446
1976	1498	1121	2619
1977	2020	1604	3624
1978	2260	1596	3856
1979	2685	2128	4813
1980	2970	2083	5053
1981	2787	1953	4740
1982	2401	1595	3996
1983	2324	1440	3764
1984	2441	1360	3801
1985	2327	1217	3544
1986	2577	1377	3954

year 1982 market mix and if the nation's driving environment was about the same as in calendar year 1985 or 1986.

Table 8-1 indicates that 2577 of the 3954 rollover fatalities in calendar year 1986 were ejectees, or 65 percent. In 1983, 62 percent of fatalities were ejected; in 1984, 64 percent; and in 1985, 66 percent. It can be concluded that about 65 percent of the 4000 baseline fatalities are ejectees, or about 2600; 1400 are killed while remaining within the car.

8.3 Combined effect of all vehicle modifications, 1963-82

Fatality risk indices for rollovers were defined in Section 7.4. The single most comprehensive index is the unadjusted one for all rollover fatalities, comprising the effects of all crashworthiness and crash avoidance changes during model years 1963-82. The actual values of the index are listed in Section 7.4, while the hatched line in Figure 7-11 traces a smooth curve through the data points. The smoothed values of the fatality index, as traced by the curve, are the following:

1963	107	1970	91	1977	96
1964	103	1971	90	1978	100
1965	100	1972	89	1979	103
1966	97	1973	88	1980	107
1967	94	1974	89	1981	115
1968	93	1975	90	1982	123
1969	92	1976	93		

A baseline fleet of all model year 1982 cars would experience 4000 rollover fatalities per year. Model year 1982 cars have a fatality index of 123. If the baseline fleet were replaced, for example, by a fleet built to 1973 technology, with the same market mix and vehicle sizes as in model year 1973, the index would drop to 88 and the number of fatalities would drop in proportion to the indices, i.e., to 4000 (88/123) = 2862. Similarly, the expected numbers of fatalities if the baseline fleet were replaced by the technology and market mix of the other previous model years would be as follows:

1963	3480	1970	2959	1977	3122
1964	3350	1971	2927	1978	3252
1965	3252	1972	2894	1979	3350
1966	3154	1973	2862	1980	3480
1967	3057	1974	2894	1981	3740
1968	3024	1975	2927	1982	4000
1969	2992	1976	3024		

A fleet of cars built with 1963 technology and the market mix characteristic of model year 1963 would experience about 3480 rollover fatalities per year in the driving environment of 1985-86, which is 520 less than the baseline of 4000 for model year 1982 cars. In other words, the combined effect of all vehicle modifications of the 1963-82 period, including the effect of smaller cars, is an increase of 520 fatalities per year. The effects of the 9 specific vehicle changes listed in Section 8.1 should add up to a net loss of 520 lives per year.

8.4 Fatality distribution within a model year, by market class

The 9 vehicle modifications whose effects have to be estimated include sales shifts among and downsizing within market classes. A necessary tool for the analysis is a historical record of the distribution of fatalities among the 7 market classes used throughout the report and defined in detail in Section 5.4:

1. Volkswagens
2. All imports other than Volkswagens
3. Domestic subcompacts
4. Domestic compacts

5. Domestic intermediates
6. Large domestic cars
7. Sporty domestic cars

Table 8-2 shows the percent of fatalities in each market class in any given model year, based on actual counts in 1975-86 FARS data. The first section of Table 8-2 enumerates rollover fatalities. For example, 1963 Volkswagens accounted for 24.7 percent of the fatalities in model year 1963 cars, while other imports accounted for 3.7 percent of the fatalities for model year 1963. The first section of Table 8-2 shows a steady decline in the proportion of fatalities that occurred in Volkswagens, from 24.7 percent in 1963 to 1.5 percent in 1982 - partly because Volkswagen has steadily lost market share, partly because they became safer. Full-sized cars' share of the fatalities has also dwindled. Imported cars and domestic subcompacts have increased their share rapidly and by 1982 accounted for well over half of the rollover fatalities. Sometimes the pattern is jumpy rather than a steady trend. For example, when new Mustangs were introduced in 1979 or Camaros in 1982, the large increase in sales touched off a corresponding growth of fatalities in market class 7.

The second section of Table 8-2 shows comparable statistics for fatalities in frontal impacts with fixed objects. As in Chapters 5-7, frontals are a control group for rollover fatalities - a measure of "market share adjusted for exposure." For example, during 1964-71, Volkswagen's share of rollover fatalities dropped from 20 percent to 7 percent while its share of frontals was consistently around 6 percent. That shows that the decline in rollover fatalities is due to safety improvements, not dwindling market share or exposure. Likewise, imported

TABLE 8-2

PERCENT OF FATALITIES IN EACH MARKET CLASS,
BY MODEL YEAR AND TYPE OF FATALITY

	1	2	3	4	5	6	7
Model Year	VW	Other Import	Sub compact	Compact	Inter mediate	Full Sized	Sporty
ALL ROLLOVER FATALITIES							
63	24.7	3.7	n.a.	24.7	9.1	36.6	1.2
64	19.9	3.9	n.a.	22.7	13.2	38.5	1.6
65	18.0	0.8	n.a.	9.3	20.6	34.5	16.2
66	15.7	3.0	n.a.	11.2	26.0	31.2	12.5
67	11.1	3.6	n.a.	8.3	24.2	31.1	21.7
68	10.3	3.3	n.a.	8.5	28.9	27.3	21.6
69	7.9	6.5	n.a.	9.8	29.1	29.1	17.4
70	5.8	7.8	n.a.	21.6	29.0	24.7	10.6
71	7.3	15.6	6.2	17.8	22.5	22.8	7.8
72	4.7	16.0	8.1	20.7	22.5	22.6	5.4
73	6.0	16.0	8.1	18.8	23.9	20.9	6.2
74	6.3	24.6	9.4	19.2	19.8	12.9	7.9
75	3.9	21.9	13.4	12.4	25.5	12.8	10.2
76	2.2	31.7	11.6	9.1	27.0	9.6	8.8
77	2.9	31.7	8.2	7.0	24.4	14.6	11.2
78	2.4	37.7	10.0	9.2	19.0	9.2	12.5
79	1.8	34.2	12.6	7.3	16.2	9.6	18.5
80	2.5	40.4	17.5	12.8	9.8	5.6	11.5
81	2.2	38.5	21.1	10.6	11.7	5.3	10.6
82	1.5	41.3	16.8	6.4	6.2	5.7	22.1
FRONTAL IMPACTS WITH FIXED OBJECTS							
63	10.7	1.7	n.a.	17.7	11.0	57.7	0.3
64	7.2	2.2	n.a.	14.7	15.8	58.9	1.3
65	6.5	0.8	n.a.	9.4	22.6	50.1	10.2
66	5.9	0.7	n.a.	8.7	28.2	47.6	8.6
67	6.7	1.9	n.a.	7.4	25.2	43.3	15.3
68	5.6	2.3	n.a.	7.7	26.6	43.1	14.6
69	6.2	3.3	n.a.	8.5	30.8	37.8	13.4
70	5.7	4.2	n.a.	17.6	29.2	32.7	10.2
71	6.5	9.9	5.4	14.1	25.1	31.5	7.4
72	4.2	11.0	7.5	15.2	25.3	31.6	5.1
73	3.4	9.7	7.8	13.8	27.4	31.9	6.0
74	4.2	14.7	9.4	18.1	27.0	17.8	8.8
75	2.9	13.4	10.1	12.9	30.3	20.7	9.7
76	1.6	17.9	11.3	11.5	29.8	17.9	10.0
77	1.7	17.8	8.2	10.5	29.4	22.8	9.5
78	1.7	21.4	10.3	10.5	25.1	18.5	12.4
79	1.4	19.6	11.8	7.8	24.3	17.5	17.7
80	1.9	27.6	18.1	14.2	16.9	10.2	11.0
81	1.5	29.7	16.9	13.6	19.9	9.1	9.2
82	1.8	27.1	18.3	10.0	16.3	9.4	17.0

TABLE 8-2 (Continued)

PERCENT OF FATALITIES IN EACH MARKET CLASS,
BY MODEL YEAR AND TYPE OF FATALITY

ROLLOVER EJECTION FATALITIES

Model Year	1 VW	2 Other Import	3 Sub compact	4 Compact	5 Inter mediate	6 Full Sized	7 Sporty
63	28.8	4.8	n.a.	26.7	8.2	30.8	0.7
64	21.6	3.2	n.a.	25.2	13.3	34.9	1.4
65	23.1	0.9	n.a.	9.8	16.8	31.7	17.0
66	19.0	4.2	n.a.	11.1	24.2	30.1	11.3
67	12.3	4.7	n.a.	9.2	22.7	27.2	23.9
68	11.1	4.3	n.a.	8.1	27.7	24.4	24.4
69	8.9	8.[illegible]	n.a.	9.5	27.7	27.1	18.5
70	5.7	9.5	n.a.	24.0	26.6	21.7	12.1
71	7.6	18.3	6.0	18.6	20.0	20.8	8.8
72	4.5	18.5	9.1	23.5	20.4	18.3	5.6
73	6.6	17.2	8.3	19.7	23.2	18.8	6.3
74	7.3	27.0	9.7	19.7	17.1	11.2	8.0
75	4.2	24.3	14.7	13.2	23.0	11.0	9.6
76	2.1	35.3	12.2	8.9	25.2	7.3	8.8
77	3.4	36.1	7.5	7.0	23.0	11.9	11.1
78	2.2	41.1	10.1	8.6	17.1	7.7	13.2
79	1.7	38.1	12.2	6.4	15.1	7.1	19.5
80	2.3	42.4	17.3	12.2	9.5	4.4	11.9
81	2.1	41.3	21.6	10.0	9.7	4.4	10.9
82	1.6	41.9	17.0	5.3	6.5	4.6	23.1

ROLLOVER NONEJECTION FATALITIES

Model Year	1 VW	2 Other Import	3 Sub compact	4 Compact	5 Inter mediate	6 Full Sized	7 Sporty
63	18.6	2.1	n.a.	21.6	10.3	45.4	2.1
64	17.8	4.7	n.a.	19.5	13.0	43.2	1.8
65	10.7	0.7	n.a.	8.7	26.1	38.5	15.1
66	11.1	1.4	n.a.	11.4	28.4	32.7	14.1
67	9.5	2.1	n.a.	7.2	26.3	36.5	18.5
68	9.3	2.1	n.a.	9.0	30.5	31.1	18.1
69	6.7	4.0	n.a.	10.4	31.1	31.8	16.1
70	5.8	5.6	n.a.	18.6	32.0	28.4	8.9
71	7.0	12.3	6.4	16.9	25.4	25.2	6.8
72	4.9	12.5	6.8	16.9	25.4	28.3	5.1
73	5.2	14.6	8.0	17.8	24.9	23.5	6.0
74	4.9	21.2	8.9	18.5	23.7	15.3	7.6
75	3.5	18.6	11.5	11.2	29.0	15.2	11.0
76	2.2	26.1	10.5	9.4	29.9	13.2	8.8
77	2.2	25.2	9.2	7.0	26.4	18.6	11.4
78	2.6	32.0	9.9	10.4	22.2	11.6	11.3
79	2.0	27.3	13.1	8.8	18.3	14.0	16.6
80	2.7	36.7	17.9	13.7	10.5	7.6	10.8
81	2.4	33.0	20.3	11.6	15.5	7.0	10.1
82	1.3	39.9	16.1	9.0	5.6	8.2	19.9

cars have a higher share of rollovers than frontals and full-sized cars, a smaller share. (For additional discussion see Section 5.1.)

The last two sections of Table 8-2 present the shares for rollover ejection and nonejection fatalities. Cars that are overrepresented among rollover fatalities usually account for an even larger share of the ejectees.

Table 8-3 combines the estimated number of overall rollover fatalities in a model year, as defined, in Section 8.3 (4000 for the baseline year 1982 and smaller numbers in previous model years) with the percentage shares of Table 8-2. It presents estimates of the numbers of rollover fatalities in each market class. For example, the baseline fleet of all 1982 model cars would have 4000 fatalities per year, of which 59 would be in Volkswagens, 1652 in other imports, etc. If it were replaced by a fleet of cars with 1963 technology and market mix, there would be 3480 rollover fatalities, of which 859 would be in Volkswagens, 129 in other imports, etc.

8.5 Estimated effects of vehicle modifications

The effects of the 9 vehicle modifications listed in Section 8.1 will be estimated one by one, starting with those easiest to calculate. Table 8-4 summarizes all the effects.

Stopping production of true hardtops: the substitution of pillared hardtops or sedans for true hardtops, as well as any other

TABLE 8-3

ESTIMATED ROLLOVER FATALITIES IN EACH MARKET CLASS, BY MODEL YEAR

(assuming car sales and exposure are the same for all model years)

	1	2	3	4	5	6	7	
MY	VW	Other Import	Sub compact	Compact	Inter mediate	Full Sized	Sporty	TOTAL
63	859	129	n.a.	859	315	1274	43	3480
64	666	130	n.a.	762	441	1290	52	3350
65	585	27	n.a.	304	670	1121	527	3252
66	495	96	n.a.	354	819	984	393	3154
67	340	109	n.a.	255	740	951	662	3057
68	312	100	n.a.	257	875	826	654	3024
69	238	194	n.a.	295	872	872	522	2992
70	170	230	n.a.	639	860	732	315	2959
71	214	456	180	522	657	668	230	2927
72	136	462	235	599	652	653	157	2894
73	170	458	233	539	685	599	177	2862
74	182	712	271	556	573	373	228	2894
75	113	641	392	362	747	373	299	2927
76	66	959	349	275	817	291	266	3024
77	90	989	256	218	762	455	351	3122
78	77	1225	327	301	618	299	406	3252
79	59	1144	421	243	544	320	618	3350
80	85	1406	609	444	341	193	401	3480
81	82	1439	790	395	437	198	398	3740
82	59	1652	670	256	249	228	885	4000

TABLE 8-4

ANNUAL EFFECT OF VEHICLE MODIFICATIONS
ON FATALITIES IN ROLLOVER CRASHES

Vehicle Modification	Date	Lives per Year Saved	Lives per Year Lost
1. Improved door locks (Standard 206)	1963-69	400	
2. Shift from 4 door to 2 door cars	1963-74		150
3. Adhesive bonding of the windshield	1963-82	40	
4. Improved suspension for Volkswagen	1967-69	280	
5. Shift to subcompact & imported cars	1970-82		1220
6. Curtailed production of true hardtops (Standard 216)	1971-77	110	
7. Downsizing of existing car lines	1975-82		350
8. Shift from 2 door back to 4 door cars	1976-82	140	
9. Wider tracks for some imported cars	1977-82	230*	
		Saved	Lost
	SUBTOTALS	1200	1720
	NET LIVES LOST PER YEAR		520

*Preliminary estimate, due to complexity of identifying the effects of individual size parameters improvements in roof crush resistance attributable to Standard 216, is a crashworthiness improvement which affects nonejection fatalities in rollovers. The _adjusted_ crashworthiness index for nonejection fatalities, as shown in Figure 6-10, measures the effect. The index dropped from 108 to 100 during the early to mid 1970's. According to Section 8.2, there are 1400 nonejection fatalities per year in a baseline fleet of model year 1982 (post-Standard 216) cars. That number would have increased to

$$(108/100)\ 1400 = 1512$$

without the improvements. Thus, the abolition of true hardtops saves approximately 110 lives per year.

Wider tracks for some imported cars: track width was found to be highly correlated with rollover propensity and, as a result, rollover fatality risk. After 1973, imported cars sold in the United States gradually became wider even though other dimensions such as weight and wheelbase stayed the same. Whatever the motivation for that change, it is associated with a fatality reduction. The average track width for market class 2 - imported cars other than Volkswagen - was 51.0 inches in model year 1973 and 53.7 inches in 1982, a growth of 2.7 inches.

According to the regression equation in Section 6.5, the coefficient for track width is -.0614. A 2.7 inch _decrease_ in track width is associated with an

$$\exp(2.7 \times .0614) - 1 = 18 \text{ percent increase}$$

in _ejection_ fatalities. The baseline number of ejection fatalities is 2600 and, according to Table 8-2, an average of 42 percent of them, or

1092 fatalities occurred in cars of market class 2 during 1980-82. If the imported cars of model year 1982 had still retained the narrower track width characteristic of 1973, these 1092 fatalities would be expected to increase by 18 percent: an extra 197 ejection fatalities.

A similar calculation is performed for the nonejection fatalities. According to the regression equation in Section 6.6, the coefficient for track width is -.0227. A 2.7 inch decrease in track width is associated with an exp(2.7 x .0227) = 6.3 percent increase in nonejection fatalities. The baseline number of nonejection fatalities is 1400 and, according to Table 8-2, an average of 37 percent of them, or 518 fatalities occurred in cars of market class 2 during 1980-82. If the imported cars had still retained the narrower track width characteristic of 1973, these 518 fatalities would be expected to increase by 6.3 percent: an extra 32 nonejection fatalities.

The sum of the reductions in ejection and nonejection fatalities equals about 230 lives saved per year. The regression models in Chapter 6 assigned a large influence to track width and less influence to wheelbase and curb weight. Because track width is highly correlated with wheelbase (.913) and curb weight (.922) in FARS, it is possible that the models partly confused their effects. In that case, the benefits of wider tracks would not be quite as large.

Shift from 2 door to 4 door cars: cars with 2 doors have significantly higher ejection risk than 4 door cars, possibly because the wider, heavier doors of a 2 door car cause a larger force to be transmitted through the door latches when the doors are impacted in a crash; also, the wider side window offers a larger portal for ejection. As a result of changes in consumer demand (viz., the baby boomers began to have children), only 45 percent of model year 1982 sales were 2 door cars, as opposed to a high of 67 percent in 1974-75. The change in consumer preference has saved lives.

According to the regression equation in Section 6.5, the coefficient for N of doors is -.122. A <u>decrease</u> from 4 to 2 doors will cause an

$$\exp(2 \times .122) - 1 = 28 \text{ percent increase}$$

in <u>ejection</u> fatalities. The baseline number of ejection fatalities is 2600 and it was achieved with a fleet of 45 percent 2 door cars and 55 percent 4 door cars. The number of fatalities that would have occurred with a fleet of all 4 door cars is calculated by solving for X in the equation

$$.45\ (1.28\ X) + .55\ X = 2600$$

X = 2309 fatalities if all cars had 4 doors. On the other hand, a fleet with 67 percent 2 door cars and 33 percent 4 door cars (the 1974-75 mix) would experience

$$.67 * 1.28 * 2309 + .33 * 2309 = 2742 \text{ ejection fatalities}$$

Thus the shift in consumer preference towards 4 door cars since 1975 saves about 140 lives per year.

Shift from 4 door to 2 door cars: From 1963 to 1974, consumer demand shifted away from 4 door cars (baby boomers began getting their first cars), resulting in a loss rather than a saving of lives. In model year 1963, only 43 percent of sales were 2 door cars. Based on the formula above, a 1982 baseline fleet with the 1963 mix of 2 door and 4 door cars would experience

.43 * 1.28 * 2309 + .57 * 2309 = 2587 ejection fatalities

Thus the shift away from 4 door cars during 1963-74 resulted in an increase of about 150 deaths per year.

Downsizing of existing car lines: During 1975-82 practically every domestic car line was redesigned with narrower track width or lighter curb weight, usually both. Even if a consumer did not shift to an imported car, but replaced a 1974 domestic car with a 1982 of the same make and model, the latter would be narrower, lighter and more rollover prone. The average reductions in track width and weight for the 5 domestic market classes from their year of greatest size through 1982 are:

	Track Width Loss	Weight Loss
Full-sized cars	3.0 inches	839 pounds
Intermediates	3.8	838
Compacts	1.2	522
Domestic subcompacts	1.8	610
Sporty cars	- .4	475

According to the regression equation in Section 6.5, the coefficient for track width is -.0614 and for curb weight, -.000188. An increase T in track width and W in curb weight is associated with a decrease of

$$1 - \exp(T \times -.0614 + W \times -.000188)$$

in ejection fatalities. According to the regression equation in Section

6.6, a similar increase in track width and curb weight is associated with a decrease of

$$1 - \exp(T \times -.0227 + W \times -.000119)$$

in <u>nonejection</u> fatalities. Thus if the 1982 cars were replaced by pre-downsized cars of the same make and market class, the expected percentage reduction in risk would be:

	Percent Fatality Reduction	
	Ejection	Nonejection
Full-sized cars	28.8	15.5
Intermediates	33.0	17.4
Compacts	15.6	8.5
Domestic subcompacts	20.5	10.7
Sporty cars	5.8	4.6

Based on Table 8-2, the average share of the fatalities held by each of the domestic classes in model years 1980-82 was:

	Percent of Rollover Fatalities	
	Ejection	Nonejection
Full-sized cars	5	8
Intermediates	9	12
Compacts	7	11
Domestic subcompacts	17	15
Sporty cars	17	14

(The remainder of the fatalities were in imported cars.) If the market mix of the baseline model year 1982 were unchanged but the 1982 model domestic cars had their track width and curb weight increased to pre-downsizing levels, the expected reduction in ejection fatalities is computed by multiplying the fatality reductions and fatality shares for the market classes - i.e.,

$$2600 \times (.288 \times .05 + .330 \times .09 + .156 \times .07 + .205 \times .17 + .058 \times .17) = 263$$

Similarly, the expected reduction in nonejection fatalities would be

$$1400 \times (.155 \times .08 + .174 \times .12 + .085 \times .11 + .107 \times .15 + .046 \times .14) = 92$$

The sum of the changes in ejection and nonejection fatalities amounts to an increase of about 350 fatalities per year. The regression models in Chapter 6 assigned a large influence to track width and less influence to wheelbase and curb weight. Because the three variables are highly intercorrelated, it is possible the models partly confused their individual effects. Nevertheless, the combined effect of the three variables, for the typical downsized car relative to the typical pre-downsized car is accurately predicted by the models.

Adhesive bonding of the windshield: NHTSA's evaluation of windshield glazing and installation methods [50] suggests that adhesive bonding and other improvements related to Standard 212 save about 100 lives per year because they reduce occupant ejections through the windshield portal (p. 239). Approximately 40 percent of occupant ejections through the windshield portal occur in rollover crashes (pp. 165-167). Thus, adhesive bonding saves approximately 40 lives per year in rollover crashes.

Improved door locks: the modifications of door locks, latches and hinges, associated with Standard 206 are crashworthiness improvements which affect ejection fatalities in rollovers. The analyses of Sections 6.5 and 7.3 yielded somewhat different effectiveness estimates, the latter higher. The lower of the two estimates will be the primary basis for estimating lives saved by improved door locks. It is based directly on FARS data without Texas data and thus ties in better with the estimate of the net effect of all vehicle modifications (Section 8.3), which is likewise based on FARS data alone. The procedure in Section 6.5, however, is limited to cars other than Volkswagens; it will need to be supplemented by a separate estimate for Volkswagen.

According to the regression equation in Section 6.5, the coefficient for the variable STD206 is -.119 - i.e., a model year 1963 car other than Volkswagen has

$$\exp(.119) - 1 = 12.6 \text{ percent higher risk}$$

in <u>ejection</u> fatalities than a 1968 or later car. This is the <u>overall</u> change in ejection fatalities and it includes the effect of adhesive windshield bonding as well as door lock improvements. The baseline number of ejection fatalities is 2600 and, according to Table 8-2, an average of 92.9 percent of them, or 2415 fatalities occurred in cars other than Volkswagens during model years 1969-71 (as explained in Section 8.1, the late 1960's rather than 1982 are used as the baseline market mix in calculations affecting Volkswagen). Without the improvements, these would have increased by:

$$.126 \times 2415 = 305 \text{ fatalities}$$

Volkswagens accounted for an average of 7.1 percent of ejection fatalities in model years 1969-71, or 185 fatalities per year if 7.1 percent is applied to the baseline of 2600. Figure 6-9 graphs the ejection risk in Volkswagens (market class 1) <u>after</u> adjustment for rollover propensity. The measure of risk decreased from +.25 in model years 1963-64 to -.30 in 1970-71. Since the rates have been adjusted for changes in rollover propensity, they measure the effect of crashworthiness improvements. The adjusted ejection risk is exp(+.25 - -.30) - 1 = 73 percent higher in 1963-64 Volkswagens than in 1970-71. Without the improvements, ejection fatalities would have increased by

$$.73 \times 185 = 135$$

The sum of the ejection reducing benefits for Volkswagens and other cars equals about 440 lives saved per year. Adhesive windshield bonding and other changes related to Standard 212 account for 40 of the lives saved. That leaves 400 lives saved per year by door lock improvements during 1963-68.

The effectiveness of Standard 206 is substantially higher in Volkswagens than in domestic cars because the latter already received major door lock improvements during 1956-63 [30], [31]. The improvements of the 1963-68 period covered in this report are only the last increments of a long term redesign process.

Another estimate of the benefits of improved door locks is based on the adjusted risk indices of Section 7.4. The adjusted crashworthiness index for ejection fatalities, as shown in Figure 6-9, dropped from 125 in model year 1963-64 to 100 by 1971. The 2600 ejection fatalities per year in a baseline fleet of model year 1982 would have increased to (125/100) 2600 = 3250 with model year 1963 door locks, windshields <u>and</u> the 1963 mix of 2 and 4 door cars. In other words, there are 650 fewer deaths in model year 1971 than in 1963. But the shift from 4 door to 2 door cars caused an increase of 150 fatalities during the same period, while adhesive windshield bonding saved 40 lives. Thus, the door lock improvements resulted in a reduction of 760 (i.e., 650 + 150 - 40) fatalities. This higher estimate, as explained above, will not be used because it is inconsistent with the overall trend in fatalities described in Section 8.3: the overall fatality reduction in model years 1963-69 was about 500, not 760. But this higher estimate could potentially be the better one if the benefits of door lock improvements prior to 1963 were added in.

Improved suspension for Volkswagen: during the mid 1960's Volkswagen redesigned its suspension system, wheels, etc. with the aim of improving directional and rollover stability [11], [32]. As shown in Figure 5-4A, these changes helped reduce the rollover rate down to the level that would be expected for a car its size, whereas before that the rate was much higher. Table 8-3 indicates that Volkswagens of model years 1964-65 averaged 625 rollover fatalities per model year (the even higher estimate for 1963 is not used since it is based on a smaller sample and may be in error). The average for model years 1969-71 is 207. That is a savings of 418 lives per year. But the data in Table 8-2 on frontal impacts with fixed objects show that the reduction is not due to shrinking market share, for Volkswagen accounted for 6-7 percent of frontal fatalities throughout 1964-71. The reduction is due to safety improvements in rollovers. It was shown above that improved door locks account for a saving of 135 lives per year in Volkswagens. The remainder of the 418 can be attributed to improvements that reduced rollover propensity - i.e., about 280 lives saved per year.

Shift to imported or subcompact cars: Table 8-4 enumerates the lives saved or lost by the vehicle modifications. Based on the analysis of the overall fatality index, it was concluded in Section 8.3 that the effects should add up to a net loss of 520 lives per year. So far estimates have been obtained for each item except the market shift to smaller car classes. Six modifications (door locks, adhesive bonding, Volkswagen suspensions, hardtop elimination, shift to 4 door cars, wider tracks for imports) have positive benefits, adding up to a subtotal of 1200 lives saved per year. The earlier shift from 4 door to 2 door cars and the downsizing within market classes are associated with an increase of 500 fatalities a year. That still leaves a gain of 700 lives saved. Since the net loss is 520, the shift to imported or subcompact cars corresponds to an increase of 1220 rollover fatalities per year.

The effect can also be estimated by methods similar to the ones used on the other modifications, providing a check for the principal estimate of 1220. The market shift to subcompact cars and imports began in earnest in 1971. A good indicator of the change is given by the proportions of frontal fixed object fatalities (control group) for the various market classes - in model year 1970 (just before the shift) and in 1981-82. The percentages are derived from Table 8-2:

	Percent of Frontal Fatalities	
	1970	1981-82
Volkswagen	6	2
Other imports	4	28
Domestic subcompacts	none	18
Compacts	18	12
Intermediates	29	18
Full-sized cars	33	9
Sporty cars	10	13

The ratio of rollover fatalities to frontal fixed object fatalities, by market class, in cars with 1980-82 size and technology, as obtained from the variable LOGROLL defined in Section 6.3, is:

	Ratio of Rollover to Frontal Fatalities
Volkswagen	1.468
Other imports	1.840
Domestic subcompacts	1.323
Compacts	.970
Intermediates	.708
Full-sized cars	.673
Sporty cars	1.317

If the passenger car fleet had the technology and car sizes characteristic of model year 1982 but the market mix characteristic of model year 1970, the number of rollover fatalities would be expected to change from the baseline of 4000 to

$$\frac{(.06\text{x}1.468 + .04\text{x}1.840 + \ldots + .33\text{x}0.673 + .10\text{x}1.317)}{(.02\text{x}1.468 + .28\text{x}1.840 + \ldots + .09\text{x}0.673 + .13\text{x}1.317)} \text{ x } 4000 = 2847$$

In other words, the market shift to imported or subcompact cars resulted in an additional 4000 - 2847 = 1153 rollover fatalities per year. This estimate compares very well with the 1220 obtained above.

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APPENDIX A

COMPLIANCE TEST RESULTS FOR STANDARD 216

Test No.	MY	Make	Model	No. of Doors/ Bodytp*	Min Crush Wt.	Min Roof Crush	Max Crush Wt.	Max Roof Crush	Curb Wt.
614100	74	AMC	GREMLIN	2	4475	1.250	4698	1.425	2983
614101	74	DATSUN	B210	2	3111	0.815	5000	1.765	2074
614030	74	CHEVY	CAPRICE	4HT	4300	4.500	4400	5.000	4671
614139	74	PLYM	FURY	4SW	5000	1.310	5250	1.400	5364
614140	74	LINCOLN	MARK4	2HT	5000	2.125	5250	2.470	5455
614141	74	CHEVY	VEGA	2	4043	2.075	4245	2.375	2695
614142	74	FORD	MAVERICK	4	4810	1.875	5050	2.015	3207
614143	74	PONTIAC	VENTURA	2	5000	1.375	5250	1.525	3782
614144	74	PONTIAC	SAFARI	4SW	5000	1.330	5250	1.405	5356
614145	74	DODGE	MONACO	4	5000	1.375	5250	1.490	4577
614202	74	PONTIAC	LEMANS	2	5000	2.825	5250	2.925	4302
614214	74	MERCURY	CAPRI	2	3715	1.325	5000	2.725	2477
614215	74	FORD	GALAXIE	2HT	5000	4.085	5250	5.250	4564
614216	74	BUICK	CENTURY	2	5000	2.250	5250	2.340	4167
614217	74	DODGE	COLT	4	3756	1.256	3944	1.400	2504
614335	74	TOYOTA	COROLLA	2	3255	1.025	3418	1.075	2170
614336	74	CHEVY	MALIBU	2	5000	2.395	5250	2.500	3875
614337	74	FORD	MUSTANG	2	4445	1.825	4667	2.925	2963
614338	74	CHRYS	NEWPORT	2HT	5000	1.445	5250	1.575	4755
614339	74	BUICK	LESABRE	2HT	5000	2.750	5250	2.875	4811
614817	75	CHEVY	CAPRI	4HT	5000	3.500	5250	3.600	4550
614862	75	CHEVY	CAMARO	2	5000	1.625	5250	3.310	3702
614863	75	FORD	PINTO	2	4616	1.863	4847	2.138	3077
614870	75	FORD	LTD	4	5000	2.125	5250	2.250	4566
614871	75	FORD	TORINO	2HT	5000	2.025	5250	2.900	4297
614872	75	FORD	GRANADA	2	5000	1.938	5250	2.088	3485
614891	75	PONTIAC	GRAND PRIX	2	5000	2.613	5250	2.713	4266
614890	75	PONTIAC	ASTRE	2SW	4007	1.475	4207	1.625	2671
614904	75	AMC	PACER	2	4716	1.088	4952	1.163	3144
614903	75	CHRYS	CORDOBA	2	5000	1.400	5250	1.550	4190
614902	75	VW	BEETLE	2	2844	1.038	2986	1.088	1896
614901	75	VW	SCIROCCO	2	2855	1.210	2997	1.290	1903

*"HT" denotes true hardtops; "SW" denotes station wagons.

Test No.	MY	Make	Model	No. of Doors/ Bodytp*	Min Crush Wt.	Min Roof Crush	Max Crush Wt.	Max Roof Crush	Curb Wt.
615013	75	DODGE	CORONET	2HT	5000	1.525	5250	1.650	4005
615042	75	BUICK	SKYHAWK	2	4413	2.025	4634	2.175	2942
615055	75	PLYM	VALIANT	2HT	4845	1.213	5087	1.313	3230
615452	76	VOLVO	245DL	4SW	4648	1.175	4880	1.250	3099
615451	76	SAAB	99GL	4	3978	1.038	4177	1.113	2652
615450	76	CHEVY	MONZA	2	4121	2.138	4327	2.313	2747
615449	76	BUICK	SKYLARK	2	5000	1.675	5250	1.738	3430
615448	76	FORD	ELITE	2HT	5000	2.263	5250	2.350	4527
615447	76	AMC	HORNET	4SW	4848	1.063	5091	1.138	3233
615570	76	OLDS	CUTLASS	2	5000	2.788	5250	2.888	4170
615569	76	DODGE	ASPEN	4SW	5000	1.263	5250	1.375	3927
615857	76	DATSUN	710	2	3704	0.825	3889	0.888	2469
615856	76	MAZDA	RX4	2	4031	1.443	4232	1.588	2687
620049	78	MERCURY	MONARCH	4	5000	2.050	5550	2.280	3460
620050	78	LINCOLN	VERSAI	4	5000	2.250	5500	2.450	3820
620051	78	PONTIAC	GRAND AM	2	4905	2.350	5400	2.650	3270
620052	78	PONTIAC	PHOENIX	2	4965	2.050	5462	2.250	3310
620053	78	PLYM	SAPPORO	2	3690	1.350	4090	1.680	2460
620054	78	TOYOTA	CRESSIDA	4	4095	1.380	4505	1.560	2730
620055	78	VW	RABBIT	4	2865	1.020	3180	1.160	1910
620056	78	PLYM	HORIZON	4	3180	1.060	3510	1.180	2120
620057	78	HONDA	ACCORD	2	2955	1.200	3280	1.370	1970
620058	78	CHEVY	MONZA	2	4020	2.140	4420	2.260	2680
624262	83	CHEVY	CAPRICE	4	5000	2.100	6005	2.600	3427
624263	83	FORD	LTD	4	4347	2.00	4770	2.62	2898
624264	84	FORD	TEMPO	4	3672	1.20	4611	1.60	2448
624265	83	FORD	T-BIRD	2	4489	1.60	5560	2.50	2993
624266	83	MERCURY	CAPRI	2	4056	3.25	4580	3.90	2704
624267	83	DODGE	600	4	3864	2.80	4600	4.10	2576
624268	83	AMC	ALLIANCE	4	2949	3.40	3428	4.90	1966
624269	83	AMC	SPIRIT	2	4156	1.60	4716	2.75	2771
624270	83	HONDA	CIVIC	2	2577	1.20	2979	1.49	1718

*"HT" denotes true hardtops; "SW" denotes station wagons.

Test No.	MY	Make	Model	No. of Doors/ Bodytp*	Min Crush Wt.	Min Roof Crush	Max Crush Wt.	Max Roof Crush	Curb Wt.
624271	83	HONDA	PRELUDE	2	3300	1.70	3700	2.01	2199
624272	83	ISUZU	IMPULSE	2	4012	2.80	4300	3.30	2675
624273	83	MAZDA	626	4	3573	1.30	4326	1.80	2382
624274	83	MITSUB	CORDIA	2	3240	1.30	3936	1.90	2160
624275	83	MITSUB	TREDIA	4	3292	1.15	4092	1.51	2195
624276	83	NISSAN	PULSAR	4	2892	1.50	3545	2.20	1928
624277	83	PONTIAC	6000	4	4107	1.20	5009	1.71	2738
624278	83	TOYOTA	CAMRY	4	3644	1.20	4504	1.60	2429
624279	83	TOYOTA	TERCEL	4	3051	1.10	4595	2.35	2034
624280	83	VW	RABBIT	2	2862	1.00	3662	1.30	1908
624281	83	VOLVO	760GLE	4	4485	2.60	5350	3.30	2990
624588	83	FORD	ESCORT	4	3222	1.07	3490	1.23	2148
624589	83	NISSAN	SENTRA	2	2856	1.17	3220	1.37	1904
624590	83	CHEVY	CHEVETTE	2	3072	1.15	3310	1.30	2048
624591	83	PLYM	TURISMO	2	3636	1.37	4150	1.63	2424
624592	83	CHEVY	CAVALIER	4	3594	1.13	4005	1.28	2396
624708	84	PONTIAC	FIERO	2	3772	2.50	4702	2.90	2515
624709	84	DODGE	DAYTONA	2	3918	1.50	4468	2.00	2612
624710	84	PLYM	CONQUEST	2	4323	3.60	5220	4.20	2882
624711	84	PLYM	COLT	4SW	3873	1.40	4585	2.00	2582
624712	84	VW	QUANTUM	4	4000	2.00	4545	2.50	2667
624713	84	MAZDA	GLC	2	2752	1.80	3293	3.40	1835
624742	84	AUDI	5000S	4	3978	1.50	4426	1.80	2652
624741	84	ISUZU	I-MARK	4	3190	1.90	3430	2.20	2127
624740	84	HONDA	CIVIC	2	2476	1.30	3081	1.60	1651
624783	84	TOYOTA	COROLLA	2	3257	2.00	3804	2.40	2171
624784	84	FORD	CROWN VIC	4	5000	4.90	5158	5.40	3658
624785	84	RENAULT	FUEGO	2	3696	2.30	4011	2.80	2464
624798	84	RENAULT	SPORTWAG	4SW	3913	2.25	4310	2.40	2609
626130	84	PEUGEOT	505	4SW	4565	1.40	5390	1.80	3043
626205	84	TOYOTA	COROLLA	4	3126	1.30	3620	1.50	2084
626206	84	NISSAN	200SX	2	3644	1.40	5000	2.10	2429

*"HT" denotes true hardtops; "SW" denotes station wagons.

Test No.	MY	Make	Model	No. of Doors/ Bodytp*	Min Crush Wt.	Min Roof Crush	Max Crush Wt.	Max Roof Crush	Curb Wt.
626207	84	HONDA	CIVIC	4SW	3032	1.50	3500	1.70	2021
626208	84	CHEVY	CELEBRITY	4SW	4329	1.40	5005	1.60	2886
626209	84	BUICK	SKYLARK	4	3941	1.30	4600	1.50	2627
626701	85	OLDS	CALAIS	2	3795	1.75	4230	1.93	2530
626784	85	CHEVY	SPECTRUM	4	2789	0.90	3140	1.10	1859
626785	85	FORD	MERKUR	2	4326	2.70	5000	3.30	2884
626786	85	DODGE	LANCER	4	4013	1.20	4700	1.50	2675
626787	85	SUBARU	GL	2	3605	2.00	4050	2.20	2403
626915	85	MITSUB	GALANT	4	4203	1.40	4624	1.60	2802
626916	85	DODGE	COLT	4	2963	1.10	3237	1.20	1975
627006	85	NISSAN	MAXIMA	4	4693	1.80	5220	2.10	3129
627253	85	CHEVY	NOVA	4	3045	1.18	3350	1.34	2030

*"HT" denotes true hardtops; "SW" denotes station wagons.

APPENDIX B

SIZES AND WEIGHTS OF CARS, BY MAKE/MODEL AND MODEL YEAR

Make/model and model year combinations present on the Texas accident files and used in analyses of Chapter 5

Track width, curb weight and vehicle height based on Automotive News Almanacs

Wheelbase derived from FARS data

Makes and models listed in the order assigned to them by the FARS make/model code (i.e., AMC, Chrysler Corp., Ford, GM, VW, followed by the other overseas manufacturers in alphabetical order, with Nissan listed under Datsun)

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
AMC-RAMBLER	63	55	2622	100	56
	64	56	2550	106	55
	65	56	2549	106	55
	66	56	2658	106	55
	67	56	2816	106	55
	68	56	2820	106	54
	69	56	2836	106	54
AMC-REBEL/MATADOR	64	58	2935	112	55
	65	58	2956	112	54
	66	58	3125	112	54
	67	58	3259	114	55
	68	58	3251	114	55
	69	60	3265	114	55
	70	60	3291	114	55
	71	60	3344	118	56
	72	60	3380	118	56
	73	60	3508	118	56
	74	60	3794	117	53
	75	60	3803	116	53
	76	60	3808	116	53
	77	60	3917	116	53
AMC-AMBASSADOR	63	58	3241	112	56
	65	58	3120	116	55
	66	58	3229	116	55
	67	59	3326	118	55
	68	59	3381	118	55
	69	60	3452	122	55
	70	60	3588	122	55
	71	60	3587	122	56
	72	60	3606	122	56
	73	60	3814	122	56
	74	60	4079	122	56
AMC-JAVELIN	68	58	3026	107	52
	69	58	3010	106	52
	70	58	3133	108	52
	71	60	3156	110	51
	72	60	3142	110	51
	73	60	3117	110	51
	74	59	3141	110	51
AMC-HORNET/CONCORD	70	57	2852	108	52
	71	57	2717	108	52
	72	57	2698	108	52
	73	57	2916	108	53
	74	57	2857	108	52
	75	57	2993	108	52

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
AMC-HORNET/CONCORD	76	57	3093	108	52
	77	58	3065	108	51
	78	58	3081	108	51
	79	57	2837	108	51
	80	57	2837	108	51
	81	58	2892	108	51
	82	58	2897	108	51
AMC-SPIRIT/GREMLIN	70	57	2635	96	53
	71	57	2630	96	52
	72	57	2572	96	52
	73	57	2728	96	53
	74	57	2762	96	52
	75	57	2757	96	52
	76	57	2766	96	52
	77	58	2806	96	52
	78	58	2748	100	51
	79	58	2603	96	52
	80	58	2663	96	52
	81	58	2767	96	52
	82	58	2693	96	52
CHRYSLER-LEBARON	77	59	3636	113	55
	78	59	3648	113	55
	79	59	3463	113	54
	80	60	3366	111	54
	81	60	3381	111	54
CHRYSLER-CORDOBA	75	62	4110	115	53
	76	62	4090	115	53
	77	62	4139	115	53
	78	62	4158	115	53
	79	62	3804	115	52
	80	60	3433	113	53
	81	60	3458	113	53
	82	60	3550	113	53
CHRYSLER-NEWPRT/NYER	63	60	4045	122	55
	64	60	4045	122	55
	65	61	4292	124	56
	66	61	4300	123	56
	67	61	4292	124	56
	68	61	4202	123	57
	69	61	4297	123	56
	70	62	4392	123	56
	71	62	4323	124	55
	72	63	4340	124	55

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
CHRYSLER-NEWPRT/NYER	73	63	4393	124	56
	74	64	4645	124	55
	75	64	4633	124	55
	76	64	4555	124	55
	77	64	4513	124	55
	78	64	4603	124	55
	79	62	3835	119	55
	80	62	3896	119	55
	82	62	3719	113	55
DODGE-DART	63	56	2658	111	54
	64	56	2797	111	54
	65	56	2772	111	54
	66	56	2860	109	53
	67	57	2889	111	54
	68	57	2929	111	54
	69	57	2938	111	54
	70	56	3039	111	54
	71	56	3004	110	54
	72	56	2973	110	54
	73	57	3040	110	54
	74	57	3168	110	54
	75	57	3159	110	53
	76	57	3072	109	53
DODGE-COR/CHG/MAG	65	59	3376	117	55
	66	59	3353	117	54
	67	59	3339	117	55
	68	59	3357	117	55
	69	59	3317	117	55
	70	59	3360	117	55
	71	61	3399	116	54
	72	61	3422	116	54
	73	62	3588	116	53
	74	62	3680	116	54
	75	62	3835	116	54
	76	62	3995	116	54
	77	62	3958	115	53
	78	62	4032	115	53
	79	62	3799	115	53
DODGE-POLARA/MONACO	63	59	3400	120	54
	64	60	3800	122	55
	65	61	4077	121	55
	66	61	4118	121	55
	67	61	4113	122	56
	68	61	3995	122	56
	69	61	3985	122	56

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
DODGE-POLARA/MONACO	70	63	4065	122	56
	71	63	4035	122	55
	72	63	4038	122	55
	73	63	4060	122	56
	74	64	4300	123	55
	75	64	4508	122	54
	76	64	4250	122	55
	77	64	3970	117	55
	78	62	3986	116	54
DODGE-CHALLENGER	70	60	3177	110	51
	71	61	3196	110	51
	72	61	3220	110	51
	73	60	3245	110	51
DODGE-ASPEN	76	59	3356	111	54
	77	59	3319	111	54
	78	59	3270	111	54
	79	59	3168	111	54
	80	60	3225	111	54
DODGE-DIPLOMAT	77	59	3636	113	54
	78	59	3603	113	54
	79	59	3462	113	54
	80	60	3357	111	54
	81	60	3388	111	54
	82	60	3444	113	54
DODGE-OMNI	78	55	2137	99	53
	79	56	2192	98	53
	80	56	2176	97	53
	81	56	2184	98	53
DODGE-MIRADA	80	60	3439	113	53
DODGE-ST REGIS	79	62	3708	119	55
	80	62	3783	119	55
DODGE-ARIES(K)	81	57	2338	100	53
DODGE-COLT	71	51	2288	95	54
	72	51	2059	95	54
	73	51	2053	95	55
	74	51	2183	95	54
	75	52	2250	95	53
	76	52	2325	95	55
	77	51	2152	95	54
	78	51	2152	95	53
	79	53	1931	94	51

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
DODGE-COLT	80	53	1838	91	51
	81	55	1927	91	50
	82	53	1922	92	50
IMPERIAL-LEBARON	64	62	4963	129	58
	65	62	5300	129	57
	67	62	5060	127	56
	68	62	4970	127	57
	69	62	4925	127	56
	70	62	4940	127	56
	71	62	4960	127	56
	72	63	5085	127	56
	73	63	5020	127	56
	74	64	4955	124	55
PLYMOUTH-VAL/DST/SCP	63	56	2675	106	53
	64	56	2703	106	53
	65	56	2761	106	54
	66	56	2752	106	53
	67	57	2811	108	54
	68	57	2825	108	54
	69	57	2867	108	54
	70	56	2959	108	54
	71	56	2943	109	54
	72	56	2919	108	54
	73	57	2985	108	54
	74	57	3100	109	54
	75	57	3082	109	53
	76	57	3069	109	53
PLYMOUTH-SATLIT/BELV	63	58	3275	116	54
	64	60	3369	116	55
	65	59	3336	116	55
	66	59	3335	116	54
	67	59	3311	116	55
	68	59	3332	116	55
	69	59	3294	116	55
	70	59	3331	116	55
	71	61	3429	115	54
	72	61	3426	115	54
	73	62	3619	115	53
	74	62	3682	115	53
PLYMOUTH-FURY	63	58	3275	116	54
	64	60	3369	116	55
	65	61	3871	119	56
	66	61	3829	120	55
PLYMOUTH-FURY	67	61	3794	120	56
	68	61	3777	119	56
	69	61	3803	120	56
	70	62	3844	120	55
	71	62	3899	121	55
	72	63	3960	120	55
	73	63	3980	120	56
	74	64	4315	121	55
	75	62	3826	116	53
	76	62	4009	116	53
	77	62	3970	116	53
	78	62	3983	116	53
PLYMOUTH-GRAN FURY	72	63	3960	120	55
	73	63	3980	120	56
	74	64	4315	122	55
	75	64	4460	122	55
	76	64	4215	122	55
	77	64	4213	122	55
	81	62	3708	119	55
	82	60	3446	113	55
PLYMOUTH-BARRACUDA	65	56	3014	106	54
	66	56	2909	106	53
	67	57	2968	108	54
	68	57	3103	108	53
	69	57	3060	108	53
	70	60	3173	108	51
	71	61	3145	108	51
	72	60	3162	108	51
	73	60	3195	108	51
PLYMOUTH-VOLARE	76	59	3367	111	54
	77	59	3311	111	54
	78	59	3266	111	54
	79	59	3166	111	54
	80	60	3221	111	54
PLYMOUTH-HORIZON	78	55	2137	99	53
	79	56	2192	98	53
	80	56	2176	97	52
	81	56	2184	98	52
PLYMOUTH-CRICKET	71	51	1966	98	55
	72	51	1961	98	55
PLYMOUTH-ARROW	76	51	2226	93	53
	77	51	2227	92	52
	78	51	2212	92	51

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
PLYMOUTH-ARROW	79	51	2272	92	51
	80	51	2272	92	51
PLYMOUTH-CHAMP/COLT	79	54	1838	91	51
	80	53	1838	91	51
FORD-FALCON	63	55	2455	110	55
	64	56	2578	110	55
	65	56	2574	110	55
	66	58	2726	112	55
	67	58	2750	112	55
	68	59	2880	112	55
	69	59	2923	112	54
	70	60	3245	112	53
FORD-FAIRLANE	63	57	3077	116	55
	64	57	3110	116	56
	65	57	3109	116	56
	66	58	3079	115	55
	67	58	3087	115	55
	68	59	3423	115	55
	69	59	3216	115	54
	70	60	3260	116	53
FORD-MUSTANG	65	56	2602	108	51
	66	56	2748	108	52
	67	58	2835	108	52
	68	58	2904	108	52
	69	59	3040	108	51
	70	59	3065	108	52
	71	61	3188	108	51
	72	61	3209	109	51
	73	61	3227	108	51
	74	56	2839	96	50
	75	56	2815	96	50
	76	56	2914	96	50
	77	56	2862	96	50
	78	56	2843	96	50
	79	57	2634	100	52
	80	57	2607	100	51
	81	57	2608	100	51
	82	57	2746	100	51
FORD-LTD II	77	64	4061	116	53
	78	64	4068	116	53
	79	64	3942	116	53

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
FORD-LTD/GALAXIE	63	61	3800	119	56
	64	61	3849	119	57
	65	62	3541	119	56
	66	62	3703	119	56
	67	62	3701	119	56
	68	62	3703	119	56
	69	64	3900	121	55
	70	64	3791	121	55
	71	64	3992	121	54
	72	64	4175	121	54
	73	64	4292	121	54
	74	64	4302	121	55
	75	64	4502	121	54
	76	64	4451	121	55
	77	64	4414	121	55
	78	64	4266	121	55
	79	62	3611	114	55
	80	62	3584	114	55
	81	62	3602	114	55
	82	62	3602	114	55
FORD-MAVERICK	69	56	2487	103	52
	70	56	2487	103	52
	71	57	2672	106	53
	72	57	2701	106	53
	73	57	2766	106	53
	74	57	2883	106	53
	75	57	2911	106	53
	76	57	3000	106	53
	77	57	3024	106	53
FORD-PINTO	71	55	2015	94	50
	72	55	2050	94	50
	73	55	2216	94	50
	74	55	2443	94	50
	75	55	2581	95	51
	76	55	2562	95	51
	77	55	2443	95	51
	78	55	2425	95	51
	79	55	2449	95	51
	80	55	2488	95	51
FORD-TORINO/GRANDE	68	59	3423	116	55
	69	59	3216	116	54
	70	60	3303	116	53
	71	60	3380	116	53
	72	63	3734	115	53
	73	63	3837	116	53
	74	63	4037	116	53

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
FORD-TORINO/GRANDE	75	63	4265	115	53
	76	63	4243	115	53
FORD-GRANADA	75	58	3366	110	54
	76	58	3449	110	53
	77	58	3393	110	53
	78	58	3291	110	53
	79	58	3262	110	53
	80	58	3269	110	53
	81	57	2933	106	53
	82	57	2938	106	53
FORD-FAIRMONT	78	57	2803	106	54
	79	57	2700	106	54
	80	57	2717	106	53
	81	57	2762	106	52
	82	57	2801	106	52
FORD-ESCORT	81	55	2050	94	53
FORD-FIESTA	78	52	1762	90	53
	79	52	1762	90	53
	80	52	1783	90	53
LINCOLN-TOWNCAR/CONTI	63	62	5135	123	54
	64	62	5257	126	54
	65	62	5275	126	54
	66	62	5285	126	55
	67	62	5255	126	55
	68	62	5180	126	55
	69	62	5208	126	55
	70	64	4910	127	56
	71	64	5062	127	56
	72	64	5116	127	56
	73	64	5210	127	55
	74	64	5195	127	56
	75	64	5277	127	56
	76	64	5225	127	56
	77	64	5052	127	55
	78	64	4836	127	55
	79	64	4843	127	55
	80	62	4090	117	56
	81	62	4104	117	56
LINCOLN-MARK	69	62	4762	117	54
	71	62	5003	117	53
	72	62	4956	120	52
	73	63	5084	120	53
LINCOLN-MARK	74	63	5246	120	53
	75	63	5353	120	53
	76	63	5227	120	53
	77	63	4871	124	53
	78	63	4757	120	53
	79	63	4783	120	53
	80	62	4144	117	56
	81	62	4097	116	56
	82	62	4046	116	56
LINCOLN-VERSAILLES	79	58	3913	110	54
MERCURY-CYCLONE	68	59	3307	116	55
	69	59	3427	116	53
	70	60	3600	117	53
	71	60	3646	117	53
MERCURY-CAPRI-DOMESTIC	79	57	2663	101	52
	80	57	2640	100	51
	81	57	2631	100	51
	82	57	2790	100	51
MERCURY-MARQUIS/MNTREY	63	61	4100	120	56
	64	61	4145	120	57
	65	62	4010	123	56
	66	62	4090	122	56
	67	62	3985	122	56
	68	62	3985	122	56
	69	64	4238	122	55
	70	64	4222	123	55
	71	64	4334	124	54
	72	64	4421	123	54
	73	64	4602	123	55
	74	64	4646	124	55
	75	64	4767	124	55
	76	64	4613	124	55
	77	64	4552	124	55
	78	64	4518	124	55
	79	62	3707	114	55
	80	62	3636	114	55
	81	62	3699	114	55
	82	62	3710	114	55
MERCURY-COMET	63	55	2615	114	55
	64	56	2989	114	55
	65	56	2907	114	55
	66	58	3073	115	55
	67	58	3113	115	55

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
MERCURY-COMET	68	59	3307	116	55
	71	57	2786	107	53
	72	57	2761	107	53
	73	57	2877	106	53
	74	57	2893	106	53
	75	57	2943	106	53
	76	57	3006	106	53
	77	57	3058	106	54
MERCURY-BOBCAT	75	55	2641	95	51
	76	55	2623	95	51
	77	55	2472	95	51
	78	55	2495	95	51
	79	55	2519	95	51
	80	55	2535	95	51
MERCURY-MONTEGO	67	58	3113	113	56
	68	59	3307	115	55
	69	59	3289	115	54
	70	60	3387	116	53
	71	60	3371	116	54
	72	63	3791	116	53
	73	63	3854	116	53
	74	63	4020	116	53
	75	63	4307	116	53
	76	63	4224	116	53
MERCURY-MONARCH	75	58	3352	110	53
	76	58	3458	110	53
	77	58	3416	110	53
	78	58	3306	110	53
	79	58	3259	110	53
	80	58	3267	110	53
MERCURY-ZEPHYR	78	57	2779	106	54
	79	57	2732	106	53
	80	57	2722	106	53
	81	57	2768	106	53
	82	57	2800	106	52
MERCURY-LYNX	81	55	2072	94	53
MERCURY-CAPRI-IMPORT	71	53	2115	101	51
	72	53	2208	101	51
	73	53	2388	101	51
	74	53	2433	101	51
	76	54	2655	101	51
	77	54	2655	101	51

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
BUICK-REGAL	63	56	2807	112	53
	64	58	3113	115	54
	65	58	3161	115	54
	66	59	3316	115	56
	67	59	3469	115	54
	68	59	3466	114	54
	69	59	3510	114	54
	70	59	3666	114	54
	71	59	3706	114	54
	72	59	3631	114	54
	73	61	3907	113	54
	74	61	4124	114	54
	75	61	3962	114	54
	76	61	3881	113	53
	77	61	3808	114	53
	78	58	3208	109	55
	79	58	3193	108	55
	80	58	3206	108	55
	81	58	3267	108	55
	82	58	3259	107	55
BUICK-LESABRE	63	62	4239	123	57
	64	62	4049	123	56
	65	63	3947	123	55
	66	63	4027	124	57
	67	63	4001	124	56
	68	63	4098	124	55
	69	63	4186	123	55
	70	63	4263	124	55
	71	64	4252	124	54
	72	64	4457	124	54
	73	64	4424	124	54
	74	64	4451	124	54
	75	64	4512	124	54
	76	64	4461	124	54
	77	61	3729	116	56
	78	61	3604	116	56
	79	61	3699	116	56
	80	61	3526	116	55
	81	61	3640	116	55
	82	61	3670	116	56
BUICK-ELECTRA	63	62	4366	126	58
	64	62	4352	126	57
	65	63	4346	126	56
	66	63	4430	126	58
	67	63	4341	126	56
	68	63	4317	126	56
	69	63	4395	126	55

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
BUICK-ELECTRA	70	63	4517	127	56
	71	64	4581	127	55
	72	64	4669	127	55
	73	64	4724	127	55
	74	64	4842	127	55
	75	64	4849	127	55
	76	64	4797	127	55
	77	61	3945	119	56
	78	61	3882	119	55
	79	61	3977	119	56
	80	61	3897	118	55
	81	61	3843	119	55
	82	61	3854	119	57
BUICK-RIVIERA	63	60	4136	117	53
	64	60	4085	117	53
	65	60	4141	117	53
	66	63	4316	119	54
	67	63	4342	119	53
	68	63	4360	119	53
	69	63	4327	119	53
	70	63	4342	119	54
	71	64	4502	122	54
	72	64	4497	122	54
	73	64	4647	122	54
	74	64	4732	122	54
	75	64	4680	122	54
	76	64	4676	122	53
	77	61	3917	116	55
	78	63	3891	116	55
	79	60	3862	114	54
	80	60	3849	114	54
	81	60	3753	114	54
	82	60	3800	114	54
BUICK-APOLLO	73	60	3342	111	54
	74	59	3420	111	53
	75	59	3511	111	53
BUICK-SKYHAWK	75	54	3013	97	50
	76	54	2992	97	50
	77	54	2894	97	50
	78	54	2886	97	50
	79	54	2861	97	50
	80	54	2868	97	51
BUICK-SKYLARK	76	59	3420	111	53
	77	59	3423	111	53
	78	59	3368	111	53

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
BUICK-SKYLARK	80	58	2515	105	52
	81	58	2515	105	54
	82	58	2554	105	54
CADILLAC-DEVILLE	63	61	4789	130	55
	64	61	4794	130	55
	65	63	4756	130	56
	66	63	4756	130	56
	67	63	4728	130	56
	68	63	4866	130	55
	69	63	4780	130	54
	70	63	4784	130	54
	71	63	4843	130	55
	72	63	4845	130	55
	73	63	4996	130	55
	74	63	5174	130	54
	75	63	5149	130	54
	76	63	5273	130	54
	77	61	4472	122	54
	78	61	4286	122	55
	79	61	4382	122	57
	80	61	4219	121	56
	81	61	4151	122	55
	82	61	3923	122	55
CADILLAC-ELDORADO	67	63	4688	120	53
	68	63	4777	120	54
	69	63	4728	120	54
	70	63	4728	120	54
	71	64	4811	126	54
	72	64	4829	126	54
	73	64	4777	126	54
	74	64	5105	126	54
	75	64	5254	126	54
	76	64	5231	126	54
	77	64	5101	126	54
	78	64	5052	126	54
	79	60	3897	114	54
	80	60	3914	114	54
	81	60	3930	114	54
	82	60	3733	114	54
CHEVY-MALIBU/CHEVELLE	64	58	3081	115	55
	65	58	3138	115	53
	66	58	3195	115	53
	67	58	3210	113	53
	68	59	3288	113	53

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
CHEVY-MALIBU/CHEVELLE	69	59	3251	114	54
	70	60	3427	114	53
	71	60	3427	114	53
	72	60	3423	114	53
	73	61	3687	114	54
	74	61	3845	114	54
	75	61	3928	114	54
	76	61	3981	114	54
	77	61	3825	114	54
	78	58	3196	108	54
	79	58	3172	108	54
	80	58	3130	108	54
	81	58	3149	108	56
	82	58	3221	108	56
CHEVY-CAPRICE/IMPALA	63	60	3530	119	56
	64	60	3555	119	56
	65	62	3644	119	55
	66	62	3649	119	55
	67	62	3696	115	55
	68	62	3695	119	56
	69	63	3794	119	56
	70	63	3883	119	56
	71	64	4011	122	54
	72	64	4171	123	54
	73	64	4303	123	55
	74	64	4354	123	55
	75	64	4318	123	55
	76	64	4361	122	55
	77	61	3769	116	56
	78	61	3788	116	56
	79	61	3720	116	56
	80	61	3473	116	56
	81	61	3586	116	56
	82	61	3609	116	56
CHEVY-CORVETTE	63	57	3037	98	49
	64	57	3110	98	50
	65	57	3135	98	50
	66	57	3140	98	50
	67	58	3155	98	50
	68	58	3210	98	48
	69	59	3245	98	47
	70	59	3285	98	47
	71	59	3292	98	48
	72	59	3305	98	48
	73	59	3407	98	48
	74	59	3390	98	48
	75	59	3529	98	48

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
CHEVY-CORVETTE	76	59	3541	98	48
	77	59	3534	98	48
	78	59	3572	98	48
	79	59	3503	98	48
	80	59	3334	98	48
	81	59	3307	98	48
	82	59	3342	98	48
CHEVY-NOVA	63	57	2674	110	55
	64	57	2725	110	55
	65	57	2766	110	55
	66	57	2791	110	55
	67	56	2805	110	55
	68	59	3039	111	53
	69	59	3069	111	52
	70	59	3093	111	54
	71	59	3127	111	54
	72	59	3145	111	54
	73	60	3289	111	54
	74	60	3331	111	54
	75	60	3471	111	54
	76	60	3364	111	54
	77	60	3334	111	54
	78	60	3342	111	54
	79	60	3329	111	54
CHEVY-CAMARO	67	59	3027	108	51
	68	59	3071	108	51
	69	60	3116	108	51
	70	61	3267	108	51
	71	61	3298	108	49
	72	61	3331	108	49
	73	61	3426	108	49
	74	61	3533	108	49
	75	61	3630	108	49
	76	61	3602	108	49
	77	61	3571	108	49
	78	61	3518	108	49
	79	61	3512	108	49
	80	61	3457	108	49
	81	61	3430	108	50
	82	61	2980	101	50
CHEVY-MONTE CARLO	70	60	3563	116	53
	71	60	3586	116	53
	72	60	3603	116	53
	73	62	3823	116	53
	74	62	4036	116	53
	75	62	4043	116	53

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
CHEVY-MONTE CARLO	76	61	4023	116	53
	77	61	3968	116	53
	78	58	3435	108	54
	79	58	3220	108	54
	80	58	3243	108	54
	81	58	3236	108	54
	82	58	3250	108	54
CHEVY-VEGA	71	55	2202	97	52
	72	55	2213	97	52
	73	55	2268	97	52
	74	55	2446	97	52
	75	54	2495	97	52
	76	54	2523	97	52
	77	54	2533	97	52
CHEVY-MONZA	75	54	2863	97	50
	76	54	2826	97	50
	77	54	2798	97	50
	78	54	2731	97	50
	79	54	2830	97	50
	80	54	2782	97	50
CHEVY-CHEVETTE	76	51	1931	94	52
	77	51	2019	94	52
	78	51	2046	96	52
	79	51	2069	96	52
	80	51	2088	96	52
	81	51	2026	95	53
	82	51	2076	96	52
CHEVY-CITATION	80	58	2508	105	53
	81	58	2513	105	54
CHEVY-CELEBRITY	82	58	2726	105	54
OLDS-CUTLASS	63	56	2747	112	53
	64	58	3229	115	54
	65	58	3339	115	55
	66	59	3347	115	55
	67	59	3353	117	54
	68	59	3453	116	54
	69	59	3470	114	54
	70	59	3568	114	54
	71	59	3540	115	54
	72	59	3523	114	54
	73	61	3871	114	54
	74	61	4012	114	54

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
OLDS-CUTLASS	75	61	3844	114	54
	76	61	3958	114	54
	77	61	3881	114	54
	78	58	3270	108	54
	79	58	3270	108	54
	80	58	3300	108	54
	81	58	3262	108	55
	82	58	3247	108	55
OLDS-DELTA 88	63	62	4239	123	56
	64	62	4084	123	56
	65	63	4051	123	56
	66	63	4045	123	56
	67	63	4097	123	56
	68	63	4113	123	56
	69	63	4210	124	56
	70	63	4136	124	56
	71	64	4286	124	54
	72	64	4363	124	54
	73	64	4368	124	54
	74	64	4515	124	54
	75	64	4544	124	55
	76	64	4481	123	55
	77	61	3725	116	55
	78	61	3705	116	55
	79	61	3744	116	55
	80	61	3612	116	55
	81	61	3676	116	57
	82	61	3671	116	57
OLDS-98	63	62	4413	126	57
	64	62	4403	126	57
	65	63	4382	126	56
	66	63	4368	126	56
	67	63	4413	126	56
	68	63	4385	126	56
	69	63	4436	127	56
	70	63	4397	127	56
	71	64	4620	127	55
	72	64	4576	127	55
	73	64	4662	127	55
	74	64	4778	127	54
	75	64	4883	127	55
	76	64	4786	127	55
	77	61	3985	119	56
	78	61	4124	119	56
	79	61	3985	119	56
	80	61	3955	119	55
	81	61	3923	119	57
	82	61	3961	119	57

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
OLDS-TORONADO	66	63	4495	119	53
	67	63	4494	119	53
	68	63	4465	119	53
	69	63	4481	119	53
	70	63	4498	119	53
	71	64	4670	122	55
	72	64	4672	122	55
	73	64	4794	122	53
	74	64	4838	122	53
	75	64	4787	122	53
	76	64	4761	122	53
	77	64	4747	122	53
	78	64	4767	122	53
	79	60	3851	114	54
	80	60	3730	114	53
	81	60	3806	114	55
	82	60	3700	114	55
OLDS-STARFIRE	75	54	3007	97	50
	76	54	2983	97	50
	77	54	2864	97	50
	78	54	2877	97	50
	79	54	2822	97	50
OLDS-OMEGA	73	59	3426	111	54
	74	59	3428	111	52
	75	60	3629	111	53
	76	60	3500	111	54
	77	60	3366	111	55
	78	60	3291	111	55
	80	58	2508	105	52
	81	58	2500	105	54
	82	58	2517	105	54
PONTIAC-LEMANS/TEMPEST	63	58	2985	112	54
	64	58	3126	115	54
	65	58	3297	115	54
	66	59	3380	115	54
	67	59	3437	115	55
	68	61	3450	113	53
	69	61	3545	113	53
	70	61	3606	113	53
	71	61	3531	113	52
	72	61	3571	114	52
	73	61	3925	113	54
	74	61	3942	113	53
	75	61	3838	113	53
	76	61	4019	114	53
PONTIAC-LEMANS/TEMPEST	77	61	3817	114	53
	78	58	3222	108	54
	79	58	3191	108	54
	80	58	3142	108	54
	81	58	3124	108	55
PONTIAC-BONNEVL/CATAL	63	63	4078	121	55
	64	64	4076	121	56
	65	64	4075	122	55
	66	64	4128	122	55
	67	64	4163	122	55
	68	64	4162	122	55
	69	64	4256	123	55
	70	64	4264	122	55
	71	64	4296	125	54
	72	64	4349	125	54
	73	64	4416	124	54
	74	64	4502	124	54
	75	64	4565	124	54
	76	64	4416	125	54
	77	61	3700	116	53
	78	61	3692	116	55
	79	61	3737	115	55
	80	61	3616	116	55
	81	61	3676	116	56
	82	58	3270	108	56
PONTIAC-VENTURA	71	59	3095	111	54
	72	59	3131	111	54
	73	60	3373	111	53
	74	60	3405	111	52
	75	60	3445	111	52
	76	61	3484	111	53
	77	61	3307	111	53
PONTIAC-FIREBIRD/TR AM	67	60	3226	108	52
	68	60	3232	108	50
	69	60	3375	108	50
	70	61	3516	108	51
	71	61	3491	108	50
	72	61	3480	108	50
	73	61	3462	108	50
	74	61	3589	108	49
	75	60	3496	108	49
	76	60	3657	108	49
	77	61	3451	108	49
	78	61	3483	108	49
	79	61	3460	108	49
	80	61	3432	108	49
	81	61	3435	108	50
	82	61	2995	101	50

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
PONTIAC-GRAND PRIX	63	63	4108	120	54
	64	64	4123	120	55
	65	64	4110	121	54
	66	64	4218	121	54
	67	64	4204	121	54
	68	64	4204	121	54
	69	61	3885	118	52
	70	61	3936	118	52
	71	61	3975	118	52
	72	61	3962	118	52
	73	62	4117	116	53
	74	62	4231	116	53
	75	61	4167	116	53
	76	61	4183	116	53
	77	61	3939	116	53
	78	58	3293	108	53
	79	58	3230	108	53
	80	58	3270	108	53
	81	58	3290	108	55
	82	58	3343	108	55
PONTIAC-ASTRE	75	54	2572	97	50
	76	55	2519	97	52
	77	55	2560	97	52
PONTIAC-SUNBIRD	76	55	2812	97	50
	77	55	2758	97	50
	78	55	2751	97	50
	79	55	2770	97	50
	80	55	2769	97	50
PONTIAC-PHOENIX	77	61	3307	111	53
	78	61	3317	111	53
	80	58	2567	105	53
	81	58	2547	105	53
	82	58	2544	105	53
VW-KARMANN GHIA	63	51	1808	95	52
	64	51	1808	95	52
	65	51	1808	95	52
	66	51	1830	95	52
	67	52	1852	95	52
	68	52	1918	95	52
	69	52	1918	95	52
	70	52	1918	95	52
	71	52	1918	95	52
	72	52	1918	95	52
	74	52	1984	95	52

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
VW-BEETLE	63	51	1631	95	59
	64	51	1631	95	59
	65	51	1631	95	59
	66	51	1719	95	59
	67	52	1764	95	59
	68	52	1808	95	59
	69	52	1808	95	59
	70	52	1808	95	59
	71	52	1807	95	59
	72	52	1807	95	59
	73	53	1826	95	59
	74	53	1896	95	59
	75	53	1896	95	59
	76	53	1970	95	59
	77	53	1970	95	59
	78	53	2110	95	59
VW-RABBIT	75	54	1830	95	56
	76	54	1900	95	56
	77	54	1900	95	56
	78	54	1940	94	56
	79	54	1940	94	56
	80	54	1900	95	56
	81	54	1900	95	56
	82	54	1900	95	56
VW-SCIROCCO	75	54	1940	95	52
	76	54	2015	95	52
	77	54	2015	95	52
	78	54	1948	95	52
	79	54	1948	95	52
	80	54	1948	95	52
	81	54	1948	95	52
	82	54	2159	95	51
VW-UNK AUTO	63	51	1639	95	59
	64	51	1646	95	59
	65	51	1640	95	59
AUDI-4000	81	56	2342	100	54
AUDI-5000	78	57	2695	106	55
	79	57	2701	106	55
	80	57	2701	106	55
	81	57	2703	106	55
AUDI-UNK AUTO	73	56	2367	105	56
	74	56	2301	101	56

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
AUDI-UNK AUTO	75	57	2182	99	55
	76	57	2108	97	55
	77	57	2150	98	55
	78	57	2329	101	55
	79	57	2295	100	55
	82	57	2201	100	55
BMW-UNK AUTO	75	57	4340	104	56
	76	57	2852	101	56
	77	57	2762	101	56
	78	57	2650	101	56
	79	57	2676	102	56
	80	57	2500	101	56
	81	57	2737	102	56
	82	57	2500	101	56
NISSAN-200 SX	77	50	2365	92	51
	78	50	2445	92	51
	79	50	2365	92	51
	80	53	2624	95	52
	81	53	2624	95	52
NISSAN-B210/1200	74	50	1945	92	53
	75	50	2055	92	53
	76	50	2095	92	53
	77	50	1998	92	53
	78	50	2020	92	53
	79	52	1983	92	53
	80	52	1960	92	53
	81	52	1960	92	53
NISSAN-240...300Z	72	53	2350	91	51
	75	53	2755	93	51
	76	53	2772	93	51
	77	53	2768	93	51
	78	53	2840	93	51
	79	54	2817	93	51
	80	54	2815	93	51
	81	54	2924	93	51
	82	55	2838	93	51
NISSAN-310	79	54	2000	94	52
	80	54	2004	94	53
	81	54	2000	94	54
NISSAN-510	71	50	2046	97	56
	72	50	2040	97	56

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
NISSAN-510	78	53	2263	95	55
	79	52	2263	95	55
	80	53	2204	95	54
NISSAN-810/MAXIMA	77	53	2659	104	55
	79	53	2753	104	55
	81	54	2800	103	55
NISSAN-UNK AUTO	65	47	1947	94	56
	68	50	2017	95	55
	69	50	2072	95	55
	70	50	2103	97	55
	71	49	1975	94	54
	72	49	1976	93	53
	73	49	2257	93	53
	74	50	2236	93	54
	75	50	2289	93	53
	76	50	2321	93	53
	77	50	2311	93	53
	78	50	2305	93	53
	79	52	2370	93	53
	80	52	2328	93	53
	81	52	2470	94	53
	82	55	2486	95	54
FIAT-BRAVA/131	76	53	2455	98	54
	79	53	2490	98	54
FIAT-128	72	51	1735	96	56
	74	52	1905	90	56
FIAT-X-1/9	80	53	2130	87	47
FIAT-STRADA	79	55	2285	96	53
FIAT-UNK AUTO	71	52	1832	87	53
	72	52	1905	90	53
	73	51	1855	90	56
	74	52	1984	90	56
	75	52	2129	91	54
	76	52	2140	92	54
	77	52	2072	89	54
	78	52	2204	92	54
HONDA-CIVIC	73	51	1536	87	53
	74	51	1605	87	52
	75	51	1718	87	52

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
HONDA-CIVIC	76	51	1721	88	52
	77	51	1714	88	52
	78	51	1713	88	52
	79	51	1727	87	52
	80	54	1751	89	53
	81	54	1842	90	53
	82	54	1864	90	53
HONDA-ACCORD	77	55	2018	94	52
	78	55	2078	94	53
	79	55	2170	94	53
	80	55	2199	94	53
	81	55	2201	94	53
	82	56	2128	97	54
HONDA-PRELUDE	79	55	2106	91	51
	80	55	2130	91	51
	81	55	2148	91	51
HONDA-UNK AUTO	72	45	1344	79	50
	73	51	1536	87	53
	74	51	1605	87	52
	75	51	1718	87	52
	76	51	1721	88	52
	77	51	1815	90	52
	78	51	1851	90	52
MAZDA-RX7	79	56	2350	95	50
	80	55	2395	95	50
	81	56	2345	95	50
MAZDA-GLC	77	51	1965	91	54
	78	51	1965	91	54
	79	51	1955	91	54
	80	51	1965	91	54
	81	55	1893	93	54
MAZDA-UNK AUTO	71	47	2103	97	53
	72	61	2249	95	54
	73	51	2259	94	54
	74	51	2501	96	54
	75	51	2628	96	53
	76	51	2436	94	53
	77	51	1990	91	54
	78	51	1974	91	54
	79	51	2274	94	54
	80	51	2330	95	54
	81	55	2226	95	54
	82	54	2317	96	54

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
MERCEDES-BASIC SEDAN	63	58	2810	106	59
	70	57	3305	113	57
	73	57	3695	112	57
	74	57	3881	106	57
	75	57	3870	112	57
	76	57	3850	104	57
	77	57	3815	97	57
	78	57	3881	102	57
	79	57	3815	97	57
	81	57	3605	97	57
MG-MIDGET	63	45	1566	80	50
	71	45	1512	80	49
	72	45	1512	80	49
	74	45	1746	80	49
	76	45	1827	80	48
	77	46	1849	80	48
	78	46	1826	80	48
	79	46	1826	80	48
MG-UNK AUTO	65	51	1884	92	53
	70	49	1920	91	50
	71	49	1793	87	50
	72	49	1757	87	50
	73	49	1964	91	50
	74	49	2113	86	49
	75	49	2045	85	51
	76	49	2005	84	51
	77	49	2214	88	51
	78	49	2207	88	51
	79	49	2124	86	51
	80	50	2335	91	51
PORS-UNK AUTO	63	51	1985	83	52
	64	51	2060	83	52
	65	51	2376	87	52
	69	53	2095	89	52
	70	53	2091	94	52
	71	54	2120	93	48
	72	54	2002	94	52
	73	53	1982	95	52
	74	53	2226	95	52
	75	53	2205	97	52
	76	53	2558	89	52
	77	53	2447	95	52
	78	55	2548	93	50
	79	55	2719	95	50
	81	55	2875	91	50

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
RENAULT-LE CAR	79	50	1819	96	55
RENAULT-UNK AUTO	69	49	1825	89	56
	71	49	1907	89	55
	72	52	2050	96	57
SAAB-UNK AUTO	72	55	2360	97	57
	73	55	2490	97	57
	74	55	2500	97	57
	76	56	2560	97	57
	77	56	2575	98	57
	79	56	2660	99	57
SUBARU-FE/GF/DL/G	80	53	2086	95	54
	81	53	2082	96	54
SUBARU-UNK AUTO	71	48	1630	95	55
	72	48	1640	95	55
	73	49	1850	97	53
	74	49	1986	97	54
	76	49	2045	96	53
	77	49	1990	97	53
	78	50	2015	97	53
	79	50	2024	97	55
	80	53	2088	95	54
	81	53	2083	96	54
	82	53	2140	96	54
TOYOTA-CORONA	68	50	2260	95	55
	69	50	2260	95	55
	70	50	2235	97	55
	71	51	2170	97	55
	72	51	2170	97	55
	73	51	2170	99	55
	74	52	2420	98	54
	75	53	2610	99	54
	76	53	2576	99	54
	77	53	2665	98	55
	78	53	2555	98	54
	79	54	2548	99	53
	80	53	2537	99	54
	81	53	2587	99	53
TOYOTA-COROLLA	69	49	1637	90	54
	70	49	1566	90	54
	71	49	1820	92	54
	72	49	1820	92	54
	73	49	1820	92	54

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
TOYOTA-COROLLA	74	49	1938	92	53
	76	51	2275	93	54
	77	51	2158	93	54
	78	51	2165	93	53
	79	52	2154	93	53
	80	52	2170	95	52
	81	52	2230	95	52
	82	52	2313	95	52
TOYOTA-CELICA	72	51	2266	96	52
	73	51	2300	96	52
	74	51	2447	96	52
	75	51	2498	96	51
	76	52	2583	98	52
	77	52	2570	98	52
	78	54	2390	98	51
	79	54	2515	98	51
	80	53	2505	98	51
	81	53	2619	98	51
	82	54	2523	98	52
TOYOTA-CARINA	72	51	1914	96	55
TOYOTA-STARLET	81	51	1724	91	54
TOYOTA-UNK AUTO	68	50	2260	95	55
	69	50	2065	94	55
	70	50	1979	94	55
	71	51	1983	94	55
	72	51	2020	95	55
	73	51	2058	95	55
	74	49	2197	94	53
	75	49	2522	96	55
	76	51	2394	95	54
	77	51	2369	96	54
	78	51	2289	96	53
	79	52	2352	96	52
	80	52	2314	97	52
	81	52	2252	97	52
	82	52	2317	97	52
TRIUMPH-SPITFIRE	75	50	1931	83	46
	80	50	1887	83	46
TRIUMPH-UNK AUTO	65	49	2072	88	50
	75	55	2203	86	50
	76	55	2189	85	50
	77	55	2219	84	50

Make/Model	Model Year	Track Width	Curb Weight	Wheel-base	Height
TRIUMPH-UNK AUTO	78	55	2070	84	50
	79	55	1856	83	50
	80	55	2231	84	50
VOLVO-UNK AUTO	63	52	2295	103	59
	64	52	2320	103	59
	65	52	2190	102	59
	67	53	2195	103	57
	68	53	2625	102	57
	69	53	2584	102	57
	70	53	2607	102	57
	71	53	2716	103	57
	72	53	2598	103	57
	73	53	2727	103	57
	74	53	2921	105	57
	75	55	2922	104	57
	76	55	3013	104	57
	77	55	2933	104	56
	78	55	2877	104	56
	79	55	2924	104	57
	80	54	2891	104	57
	81	55	2891	104	56
	82	55	2879	104	56

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