Correlation of Vehicle Performance in the New Car Assessment Program with Fatality Risk in Actual Head-On Collisions

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ABSTRACT

The New Car Assessment Program (NCAP) has gauged the performance of vehicles in frontal impact tests since model year 1979. NCAP test speeds and impact locations closely resemble the conditions in a large proportion of actual frontal crashes that result in fatalities or serious injuries. The relationship between NCAP test scores and actual fatality risk on the road was studied. Head-on collisions between two 1979-91 passenger cars in which both drivers wore safety belts were selected from the 1978-92 Fatal Accident Reporting System. There were 396 collisions (792 cars) in which both cars were identical with or very similar to vehicles which had been tested in NCAP. In the analyses, adjustments were made for the relative weights of the cars, and for the age and sex of the drivers.

There are statistically significant correlations between NCAP scores for head injury, chest acceleration and femur loading and the actual fatality risk of belted drivers. In a head-on collision between a car with good NCAP score and a car of equal weight with a poor score, the driver of the car with the better NCAP score has, on average, a 15 to 25 percent lower risk of fatal injury. Cars built from 1979 through 1982 had, on the average, the poorest NCAP scores. Test performance improved substantially from 1983 onwards. In parallel, fatality risk for belted drivers in actual head-on collisions decreased by 20 to 25 percent in model years 1979-91, with the largest decreases just after 1982. The paper concludes with a survey of possible future goals for NCAP.

INTRODUCTION

The Fiscal Year 1992 Report of the Appropriations Committee of the United States Senate and the Senate-House Conference Committee Report required the National Highway Traffic Safety Administration (NHTSA) to implement improved methods to inform consumers of the comparative levels of safety of passenger vehicles as measured in the New Car Assessment Program (NCAP) and to examine and study the results of previous model year NCAP results to determine the validity of these test data in predicting actual on-the-road injuries and fatalities.[1] In December 1993, NHTSA presented a report to Congress that responded to these requirements.[2] NHTSA issued a technical report in January 1994, which analyzed the correlation of NCAP performance with fatality risk in actual head-on collisions.[3] Analyses, findings and conclusions of the Congressional and technical reports are summarized in this paper.

Brief History of the New Car Assessment Program

In 1978, NCAP was initiated with the primary purpose of partially fulfilling one of the requirements of Title II of the Motor Vehicle Information and Cost Savings Act of 1973.[4] The purpose of this requirement was to provide consumers with a measure of relative crashworthiness of passenger motor vehicles. NHTSA concluded that by using existing technical approaches, safety information on the relative crashworthiness that vehicles provide in frontal crashes could be developed. This provided consumers with important information to aid them in their vehicle purchase decisions. The ultimate goal of NCAP was to improve occupant safety by providing market incentives for vehicle manufacturers to voluntarily design better crashworthiness into their vehicles, rather than by regulatory directives.

In this program, vehicles are subjected to a frontal crash test. The vehicles are towed head-on into a fixed, rigid barrier at 35 mph. Each vehicle carries two instrumented anthropomorphic test devices (dummies) that simulate 50th percentile adult males. These dummies are located in the front driver and front-right passenger seats and are restrained by the vehicle's safety belts and air bags, if available. During the crash, measurements are taken from each dummy's head, chest, and upper legs. These measurements are used as surrogates for the likelihood of serious injury and, thereby, the relative crashworthiness of the vehicle in a severe frontal impact.

The testing protocol used by NCAP is based on years of development work conducted by NHTSA, the automobile industry, and others to create the test devices and test procedures used in determining compliance with Federal Motor Vehicle Safety Standard (FMVSS) No. 208, "Occupant

Crash Protection."[5] This standard requires that certain injury criteria, as measured by the dummies, not be exceeded in a 30-mph frontal crash test. The injury criteria apply to the head (as measured by a composite of acceleration values known as the Head Injury Criterion or HIC), chest (as measured by a chest deceleration value known as chest G), and upper legs (as measured by compressive forces on each of the femur bones). These criteria are used to assess the performance of the vehicles tested in the NCAP.

The NCAP crash tests are conducted at 35 mph in order to provide a level of impact severity sufficiently higher than the FMVSS 208 requirement at 30 mph so that differences in frontal crashworthiness performance among vehicles can be more readily observed. Since kinetic energy is proportional to the square of the velocity, there is 36 percent more kinetic energy in a 35-mph crash than one at 30 mph. Another measure of severity in a frontal, fixed barrier test is the total instantaneous change in velocity of the vehicle (known as delta V), including the rebound from the barrier. In the 35-mph NCAP test, the average delta V is 40 mph, including the rebound velocity from the barrier. In a 30-mph test, the average delta V is 33 mph.

From an analysis of the National Accident Sampling System's (NASS) files, the relationships of delta V to injury and fatalities have been developed for passenger car drivers restrained by available belt systems (no air bag equipped vehicles are included).[6] These data are shown in Figures 1 and 2. Curves are given for Abbreviated Injury Scale (AIS) 3 and greater injuries, AIS $\geq$ 4 injuries, and fatalities.[7] AIS 3 injuries are serious but often not life-threatening with emergency care. AIS $\geq$ 4 injuries are severe and life-threatening. AIS $\geq$ 4 injuries to the head may include severe skull fractures and/or brain injury. AIS $\geq$ 4 injuries to the thorax may include severe damage to the lungs, torn aortas, or massive collapse of the rib structure.

The NASS data indicate that the fatality and injury rates for restrained, front-seat drivers are several times greater in a crash with a 40-mph delta V than in a crash with only a 33-mph delta V (See Figure 1). The NASS files also show that approximately 50 percent of the life-threatening injuries and nearly 80 percent of the fatalities of restrained drivers in frontal collisions occur in crashes with a delta V greater than 33 mph (See Figure 2). As in the real-world crashes, the injury data obtained in the 35-mph crash tests show a much greater injury potential and a much greater spread among the safety performance measures of various vehicles than observed in the 30-mph crash tests.

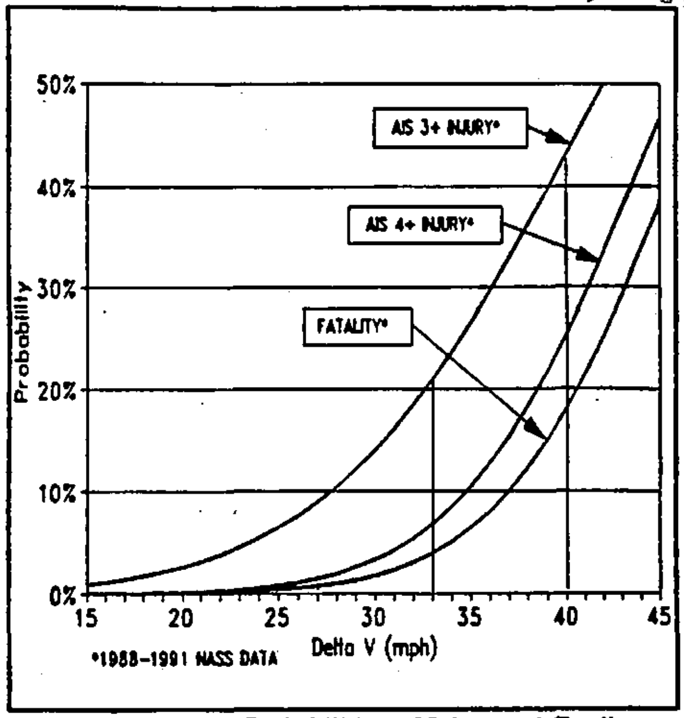

Figure 1. Estimated Probabilities of Injury and Fatality for Restrained Drivers in Frontal Collisions.

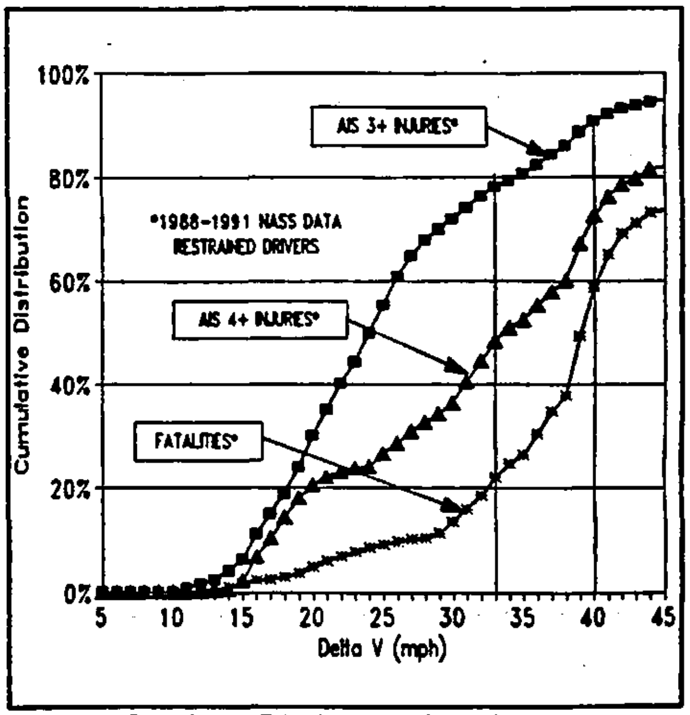

Figure 2. Cumulative Distribution of Injuries and Fatalities for Restrained Drivers in Frontal Crashes.

The first NCAP press release was issued on October 16, 1979. Since that time, more than 440 different passenger cars, light trucks, vans, and sport utility vehicles have been tested. Presently, the tested makes and models of passenger cars represent more than 50 million of the passenger cars on the road today. Notable improvements in occupant safety as measured by the dummy responses have occurred during the history of the program, as summarized in section on historical performance in NCAP. These improvements have been associated with significant reductions in the fatality risk of restrained drivers of passenger cars involved in severe frontal crashes, as will be shown in the accident analysis sections of this paper.

Review of NHTSA's Plan as Proposed to Congress in the February 1992 Report

In the Fiscal Year 1992 Senate and Conference Appropriations Reports,[1] NHTSA was required to utilize a variety of new methods in presenting NCAP data in order to make the data more easily understandable by consumers and more useful as a market incentive. The Committees proposed that these methods may include publications of lists of vehicle models performing best and worst on different injury criteria, lists of vehicle models with the highest and the lowest HIC, lists of vehicle models in rank order of their performance on NCAP tests, and the historical performance of different automobile manufacturers on NCAP tests.

In response, NHTSA proposed to: (1) develop a report of the historical performance of the different automobile manufacturers in NCAP, (2) analyze the NCAP data base and determine an appropriate format for presenting the various suggestions for new lists, (3) evaluate the potential impact of these presentation methods on the car-buying public and evaluate the vehicle safety needs and choices of the automobile consumers through the use of consumer focus groups and (4) enlist the help of media experts to determine improvements in NCAP data presentations.[8] The report of the historical performance of the different automobile manufacturers in NCAP was completed and delivered to the Committees and then made available to the public in September 1993.[9] It is summarized in the next section of this paper. A simplified NCAP data presentation format was developed and focus groups were conducted to evaluate consumer reactions. A review of the focus group studies along with the results of the media survey may be found in the December 1993 report to Congress.[2]

The Committees also requested a study to analyze the results of NCAP data from previous model years to determine the validity of these tests in predicting actual on-the-road risk of injuries and fatalities over the lifetime of the models. In an attempt to fulfill the Committees' requirements, NHTSA proposed to examine data contained in NASS, Fatal Accident Reporting System (FARS), and individual state accident files, and analyze "hard-copy" (i.e., written) reports of crashes to evaluate and compare on a one-to-one basis the performance of specific models which have been tested in NCAP and also have been involved in high-severity frontal impacts on the highway. Those studies are summarized in this paper.

HISTORICAL PERFORMANCE OF DIFFERENT AUTO MANUFACTURERS IN NCAP

In the September 1993 historical NCAP report, trends of improved vehicle safety performance as measured by NCAP were provided.[9] These trends, based on the dummy HIC and chest G responses are shown in Figure 3 for all tests of passenger cars that have been conducted through MY 1993. The average values for the dummy response parameters are given for each model year. Also, the averages for the fleet of NCAP-tested passenger cars, as determined from vehicle registrations, are shown for each year. (Note: After the first year of NCAP testing, this fleet included approximately two million of the passenger cars on the road. At the conclusion of the MY 1992 NCAP testing, this fleet included over 52 million of the registered passenger cars. The file has not yet been updated with vehicle registrations for MY 1993. Therefore, weighted values are only available through MY 1992.) Conspicuous downward trends are shown for each of the injury parameters.

In Tables 1 and 2, summary information from the September historical report on the different motor vehicle manufacturers is given. These data include: the number of vehicles which have been tested, the percentage of vehicles which have met FMVSS 208 requirements (HIC's not exceeding 1,000, chest G's not exceeding 60, and femur loads not exceeding 2,250) in the higher-speed NCAP tests, and overall average values for the driver HIC, passenger HIC, driver chest G, and passenger chest G. For passenger cars, where adequate data exist, this information also is given for two time periods, MY 1979 through MY 1986 and MY 1987 through MY 1993. The phase-in of the automatic occupant protection requirements of FMVSS 208, beginning in MY 1987 led to extensive use of air bags as supplemental restraints, which further improved the safety performance of passenger cars in NCAP.

Substantial reductions in average driver HIC and passenger HIC values have occurred in MY 1987 through 1993 passenger cars when compared to MY 1979 through 1986 passenger cars. The average driver HIC values along with these reductions for the 6 major manufacturers are graphically shown in Figure 4.

A much higher percentage of passenger cars are now meeting the requirements of FMVSS 208 at the higher NCAP crash speed. Almost 80 percent of the passenger cars tested in NCAP during 1993 met the FMVSS 208 requirements. These historical records and the trends shown in Figure 3, indicate that:

- The vehicle manufacturers have the knowledge and capability to design passenger cars that achieve excellent scores in the severe 35-mph crash test if all occupant protection systems are used
- With the phase-in of automatic occupant protection beginning with MY 1987, the vehicle manufacturers notably improved occupant protection in 35 mph crashes as measured by the dummy responses.

TABLE 1. NCAP - SUMMARY DATA ON PASSENGER CARS

MANUFACTURER	NO. OF CARS TESTED		% MEETING FMVSS NO. 208 CRITERIA			DRIVER HIC AVERAGE			PASSENGER HIC AVERAGE			DRIVER CHEST G AVERAGE			PASSENGER CHEST G AVERAGE		
	MODEL YEARS		MODEL YEARS			MODEL YEARS			MODEL YEARS			MODEL YEARS			MODEL YEARS		
	ALL	87-93	ALL	79-86	87-93	ALL	79-86	87-93	ALL	79-86	87-93	ALL	79-86	87-93	ALL	79-86	87-93
GM	71	33	59	61	58	858	897	812	806	802	811	46	44	48	40	39	42
FORD	61	22	48	19	89	920	1090	693	796	1018	500	52	55	47	44	47	41
CHRYSLER	44	20	48	38	61	969	1111	799	974	1069	853	50	51	48	44	43	45
TOYOTA	29	13	62	62	62	883	910	849	753	853	631	50	50	51	47	48	44
NISSAN	25	15	40	20	53	982	1142	874	939	1301	697	53	56	51	48	50	43
HONDA	26	17	69	50	81	909	1176	738	795	1016	652	49	49	49	41	38	43
VOLKSWAGEN	17	6	19	10	33	1138	1250	945	958	911	1035	53	54	52	45	44	45
MAZDA	12	7	58	0	100	881	1065	750	1012	1445	703	56	60	51	48	49	48
MITSUBISHI	10	7	78	67	83	891	879	897	830	1168	685	64	62	60	44	45	44
PEUGEOT/RENAU	13	4	0	0	0	1908	1957	1793	1868	2011	1577	59	58	60	49	47	52
VOLVO	7	2	86	80	100	742	879	400	700	724	640	41	42	40	39	39	40
HYUNDAI	8	7	25	0	29	888	1000	871	971	2682	729	58	73	53	45	55	44
ISUZU	5	2	0	0	0	1570	1821	1194	1523	1711	1240	47	42	54	48	47	48
SUBARU	8	4	38	25	50	1055	1230	880	988	1293	682	53	54	51	48	49	43
MERCEDES	3	1	33	0	100	984	1078	800	979	1052	833	59	58	60	49	44	58
SAAB	5	3	40	0	67	658	754	594	1029	1304	846	48	55	43	38	40	37
BMW	3	2	33	0	50	1093	1539	870	622	547	698	49	42	52	40	39	40
TOTAL	339	165	50	37	63	967	1101	826	905	1055	746	50	51	49	44	44	44

TABLE 2. NCAP - SUMMARY DATA ON LIGHT TRUCKS, VANS & SPORT UTILITY VEHICLES (LTVS)

MANUFACTURER	NO. OF LTVS TESTED	% MEETING FMVSS NO. 208	DRIVER HIC AVERAGE	PASSENGER HIC AVERAGE	DRIVER CHEST G AVERAGE	PASSENGER CHEST G AVERAGE
		MODEL YEARS	MODEL YEARS	MODEL YEARS	MODEL YEARS	MODEL YEARS
		ALL	ALL	ALL	ALL	ALL
GM	21	29	1274	1215	60	49
FORD	17	44	1124	901	52	47
CHRYSLER	18	44	857	1005	51	45
TOYOTA	12	8	1250	828	55	50
NISSAN	8	38	1080	810	54	46
VOLKSWAGEN	3	0	1507	874	58	49
MAZDA	3	33	1002	857	55	46
MITSUBISHI	6	50	1203	978	52	54
ISUZU	10	10	1282	1207	61	59
SUZUKI	3	33	1214	1548	62	53
TOTAL	101	31	1150	1020	55	49

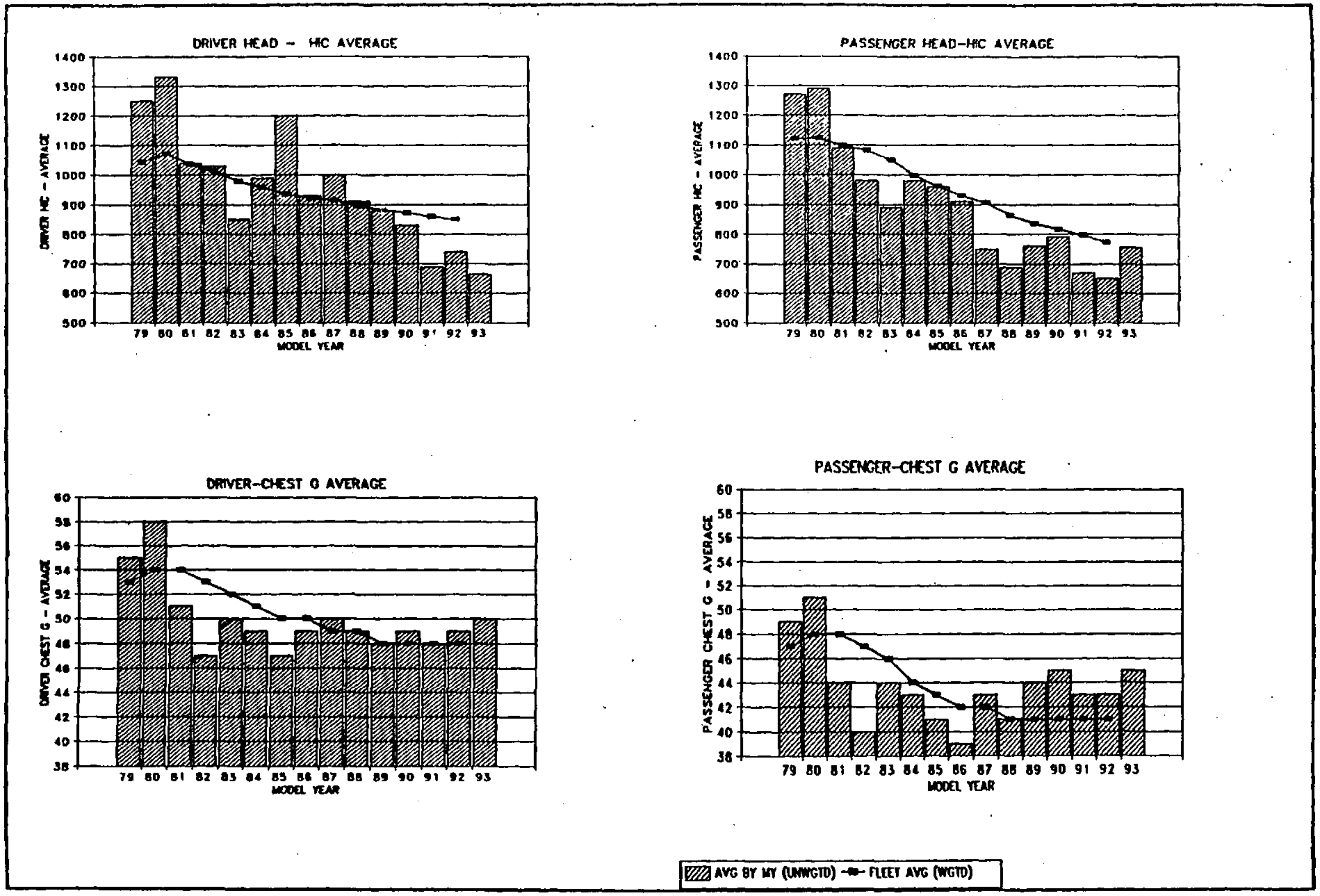

Figure 3. NCAP Dummy Response Trends for Passenger Cars

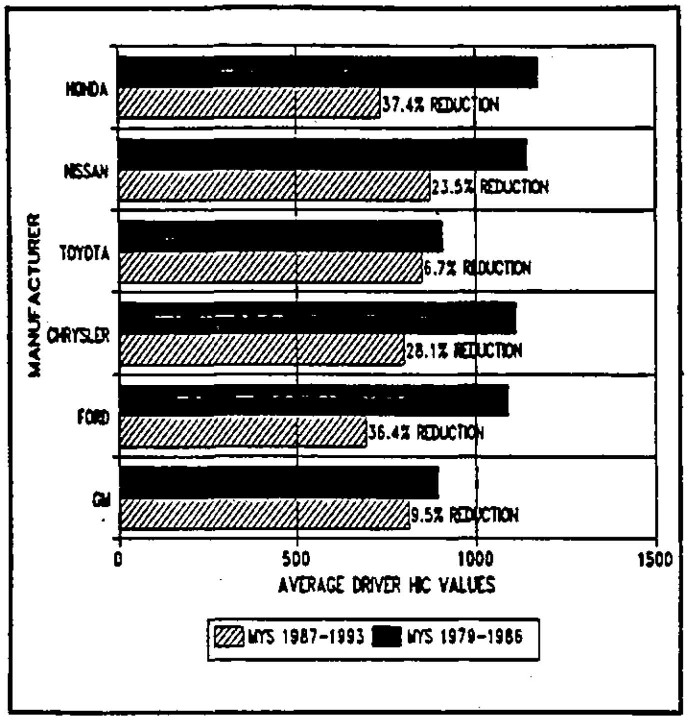

Figure 4. Average NCAP Driver HIC Values with the Percentage Reduction when Comparing MY 1987-1993 Passenger Cars to MY 1979-1986 Passenger Cars.

CHARACTERISTICS OF FRONTAL CRASHES IN THE NATIONAL ACCIDENT SAMPLING SYSTEM

In response to the Congressional Committees' request to correlate NCAP test results with fatality and injury risk in actual crashes, NHTSA examined data contained in State accident files, the National Accident Sampling System (NASS),[6] and the Fatal Accident Reporting System (FARS).[10] State files have large samples, but are of limited utility because they do not identify which injuries are serious or life-threatening. Also, the accuracy of belt-use reporting is questionable in some cases. NASS contains detailed information on occupant injuries and belt use, but the number of serious-injury crashes on the file is insufficient to analyze the correlation of injury risk with NCAP test results. On the other hand, the NASS data are quite useful for tabulating frequency distributions of severe frontal crashes and comparing the characteristics of actual crashes to NCAP test conditions. Two of the more important crash parameters for frontal crashes are the change in velocity (delta V) which occurs during the impact and the impact configuration. As previously noted, the NCAP tests result in delta Vs of approximately 40 mph and the NCAP crash configuration is a full-frontal barrier impact.

Crash Severity

Figure 2 graphs the cumulative distributions of injuries and fatalities by delta V, as found in the NASS file for restrained drivers in frontal towaway crashes. These data indicate that almost 60 percent of the fatalities and approximately 90 percent of the serious injuries for restrained drivers occur below the NCAP delta V of 40 mph. Assuming that NCAP results reflect the relative potential safety that a vehicle provides for belted occupants within 5 mph of the NCAP delta V (i.e., the NCAP data are applicable from 35- to 45-mph delta V), nearly 50 percent of the fatalities occur within this range.

Crash Type

The NCAP test configuration is based on FMVSS 208. This configuration is a full-frontal crash into a fixed-rigid barrier. This is approximately the same as two similar vehicles colliding head-on. Such collisions result in extensive damage across the full front of the vehicle and expose the occupants to high forces which must be effectively controlled by the restraint systems and the gradual deformation of the vehicle structure in order to prevent serious or fatal injury.

In Figures 5 and 6, NASS data provide insight into the relationship of real-world crash configurations to this laboratory test condition. In Figure 5, it is seen that more than 70 percent of the real-world frontal crashes which result in AIS 3 or greater injuries have a direction of force of 12 o'clock or head-on. In Figure 6, it is shown that 54 percent of the frontal crashes have induced or direct damage across the full front of the vehicle and another 27 percent have induced or direct damage which extends two-thirds of the way across the front of the vehicle.

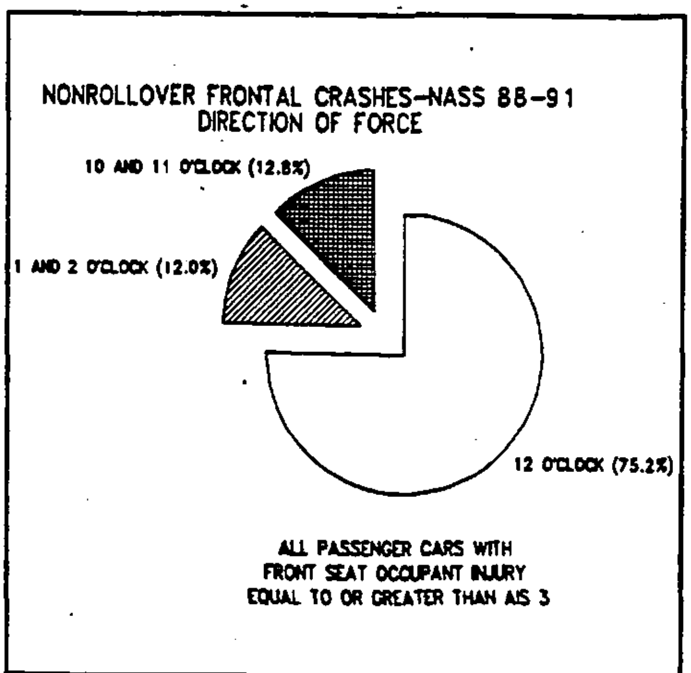

Figure 5. Frontal Impact Direction of Force from 1988-1991 NASS - Retrained and Unrestrained Front Seat Occupants

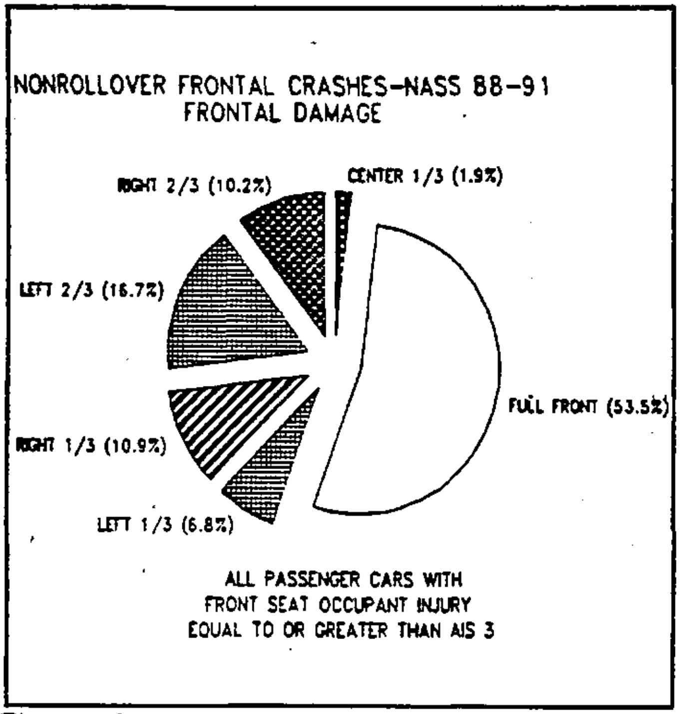

Figure 6. Frontal Impact Damage Pattern from 1988-1991 NASS - Restrained and Unrestrained Front Seat Occupants

These NASS data indicate that the FMVSS 208 and NCAP test configurations reflect closely the real-world frontal crash configurations which result in the largest number of serious injuries and fatalities.

CORRELATION OF NCAP SCORES WITH FATALITY RISK IN ACTUAL HEAD-ON COLLISIONS

The historical trends presented earlier in this paper are overwhelming evidence that vehicle performance on the NCAP test has improved since the inception of the program. Still, that evidence, by itself, does not prove that cars have become safer in actual crashes on the highway. The ultimate goal of all safety programs, including consumer information programs such as NCAP is the reduction of deaths and injuries on the highway. There is a desire for evidence that cars with good NCAP scores are safer in actual crashes than cars with poor scores, and, more generally, that cars have become safer in actual crashes since the beginning of NCAP. Researchers have eagerly explored the correlation between NCAP performance and fatality or injury risk in actual crashes since the initial years of NCAP, but have had limited success in the past due to the shortage of accident data involving restrained occupants.[11] Thanks to the steady increase in belt use in the United States after 1984, as more and more States enacted belt use laws, enough accident data involving belted occupants have accumulated in the Fatal Accident Reporting System (FARS) for meaningful statistical analyses of fatality risk, although data in other accident files are still insufficient for studies of the relationship of NCAP scores to the risk of nonfatal injuries.

The Appropriations Act for Fiscal Year 1992 directed "NHTSA to provide a study to the House and Senate Committees on Appropriations comparing the results of NCAP data from previous model years to determine the validity of these tests in predicting actual on-the-road injuries and fatalities over the lifetime of the models."[1] The agency responded with a set of analyses demonstrating a statistically significant correlation between NCAP performance and the fatality risk of belted drivers in actual head-on collisions.[3] NHTSA's goal was to see if cars with poor NCAP scores had more belted-driver fatalities than would be expected, given the weights of the cars, and the age and sex of the drivers involved in the crashes. Without adjustment for vehicle weight, driver age and sex, the large diversity of fatality rates in accident data mainly reflects the types of people who drive the cars, not the actual crashworthiness of the cars. For example, "high-performance" cars popular with young male drivers have an exceptionally high frequency of fatal crashes - because they are driven in an unsafe manner - even though they may be just as crashworthy as other models. NHTSA's analysis objective was to isolate the actual crashworthiness differences between cars, removing differences attributable to the way the cars are driven, the ages of the occupants, etc., and then to correlate NCAP performance with crashworthiness on the highway.

Analysis Overview

Since NCAP is a frontal impact test involving dummies protected by safety belts, the agency limited the accident data to frontal crashes involving belted occupants. However, NHTSA did not consider all types of frontal crashes, but further limited the data to head-on collisions between two passenger cars, each with a belted driver, which resulted in a fatality to one or to both of the drivers. A head-on collision is a special type of highway crash ideally suited for studying frontal crashworthiness differences between two cars. Both cars are in essentially the same frontal collision. It doesn't matter if one of them had a "safe" driver and the other, an "unsafe" driver; at the moment they collide head-on, how safely they were driving before the crash is nearly irrelevant to what happens in the crash. Which driver dies and which survives depends primarily on the intrinsic relative crashworthiness of the two cars, their relative weights, and the age and sex (vulnerability to injury) of the two drivers.[12]

If car 1 and car 2 weigh exactly the same, and both drivers are the same age and sex, the likelihood of a driver fatality in a head-on collision would be expected to be equal in car 1 and car 2. If car 1 and car 2 have different weights, etc., it is still possible to predict the expected fatality risk for each driver in a head-on collision between these two cars. The relationship between fatality risk and vehicle weight, driver age and sex is calibrated from the accident data by a logistic regression.[13] The expected fatality risk for driver 1 is

$$\frac{\exp[.616 - 5.427(\log W_1 - \log W_2) + .0531(A_1 - A_2) + .34(F_1 - F_2)]}{1 + \exp[.616 - 5.427(\log W_1 - \log W_2) + .0531(A_1 - A_2) + .34(F_1 - F_2)]}$$

where W_1 is the curb weight of car 1, A_1 is the age of driver 1 and F_1 is 1 if driver 1 is female, 0 if male. The expected fatality risk for driver 2 is

$$\frac{\exp[.616 + 5.427(\log W_1 - \log W_2) - .0531(A_1 - A_2) - .34(F_1 - F_2)]}{1 + \exp[.616 + 5.427(\log W_1 - \log W_2) - .0531(A_1 - A_2) - .34(F_1 - F_2)]}$$

These formulas measure the relative vulnerability to fatal injury of the two drivers, given that their cars had a head-on collision. The risk is greater in the lighter car than the heavier car, and the older or female driver is more vulnerable to injury than the younger or male driver. The formulas do not address the propensity of cars to get involved in head-on collisions as a function of driver age, sex, etc. For example, given 100 fatal head-on collisions between 3000 pound cars driven by belted, 20-year-old males and 2500 pound cars driven by belted, 50-year-old females, the formulas predict 9 deaths among the young males in the heavier cars and 97 deaths among the older females in the lighter cars (for a total of 106 fatalities in the 100 collisions, since some of them resulted in fatalities to both drivers).[14]

Cars with average crashworthiness capabilities will experience an actual number of fatalities very close to what is predicted by these formulas, which are calibrated from the collision experience of production vehicles. If a group of cars, however, consistently experiences more fatalities than expected in their head-on collisions, then the empirical evidence suggests that this group of cars is less crashworthy than the average car of similar mass. The gist of the analyses is to see if groups of cars with poor NCAP scores have significantly more belted-driver fatalities per 100 actual head-on collisions than expected (and there are several ways to define a "poor" score). The analyses measure the reduction in fatality risk, in actual head-on collisions, for a car with good NCAP scores relative to a car with poor NCAP scores. They measure the overall reduction in fatality risk, for belted drivers in head-on collisions, since model year 1979, when NCAP testing began, until 1991, the latest model year for which substantial accident data were available as of mid-1993.

The analyses require a data file of actual head-on collisions, with both drivers belted, resulting in a fatality to at least one of the drivers, indicating, for both cars, the curb weight, the driver's age and sex, and the HIC, chest G's and femur loads that were recorded for the driver dummy when that car was tested in NCAP. FARS, a census of fatal crashes in the United States, from 1978 through mid-1992, provided the basic accident data for the study.[10] Accurate curb weights are indispensable, because the relative fatality risk for two vehicles in a head-on collision is highly sensitive to the relative weight. The FARS data were supplemented with accurate curb weights, derived from weights specified in R. L. Polk's National Vehicle Population Profile[15] as well as actual weights measured in NHTSA FMVSS compliance tests on production vehicles.[16] Insufficient NCAP and FARS data were available to include light trucks, vans or sport utility vehicles in the analyses. Thus, the study is limited to collisions between two 1979-91 passenger cars.

NHTSA staff reviewed the cars involved in head-on collisions on FARS and identified, where possible, the NCAP test car that came closest to matching the FARS case. They found 396 head-on collisions, involving 792 cars, in which both drivers were belted and both cars match up acceptably with an NCAP case: (1) The make-models on FARS and NCAP are identical or true "corporate cousins" (e.g., Dodge Omni and Plymouth Horizon). (2) The model years on FARS and NCAP are identical, or the FARS model year is later than the NCAP model year, but that model was basically unchanged during the intervening years. The FARS cases were supplemented with the matching NCAP test results for each car. The sample is large enough for a statistical analysis of NCAP scores and fatality risk.[17]

Whereas FARS data can be used to distinguish head-on collisions from other crashes, they currently do not identify the impact speeds in the collisions or the exact alignment of the vehicles. FARS data do not single out those head-on collisions that would essentially duplicate an NCAP test: perfectly aligned collisions of two nearly identical cars, with minimal offset, a closing speed close to 70 mph. (Nevertheless, the NASS data showed that many fatal frontal crashes extensively resemble an NCAP test: approximately 50 percent of the fatal frontal crashes for restrained drivers occur within 5 mph of the NCAP delta V, and most severe frontal crashes involve damage across a large portion of the front of the vehicle.) Other major differences between NCAP tests and actual crashes include:

- Differences between the physical characteristics of the human driver population and the anthropomorphic dummy (the dummy represents a 50th percentile male)
- Variations in the vulnerability to fatal injury due to age and sex[18]
- Location of the fatal lesions (injury parameters are measured only in the head, chest, and femurs of the dummies in NCAP, and not directly on the neck or abdomen)

It is inappropriate to expect perfect correlation between NCAP test results and actual fatality risk in the full range of head-on collisions represented in the FARS sample. Moreover, if there is any significant correlation between the two, it would suggest that the NCAP scores say something about actual crashworthiness in a range of crashes that goes far beyond the specific type tested in NCAP. It would also uphold the premise that vehicles which meet the FMVSS 208 criteria in crash tests are safer in actual crash tests than vehicles that do not meet these criteria.

Correlation of NCAP Scores and Fatality Risk

The goal of the analysis is to test if cars with poor scores on the NCAP test have higher fatality risk for belted drivers, in actual head-on collisions, than cars with good or acceptable scores. There are many ways to define "poor" and "good" scores and measure the difference in fatality risk. All of the methods tried out by NHTSA staff demonstrate a statistically significant relationship between NCAP scores and actual fatality risk, as shown in Table 3.

Table 3

Collisions of Cars with "Good" NCAP Scores into Cars with "Poor" NCAP Scores
(N of crashes approximately 120 in each analysis)

"Good" NCAP Performance	"Poor" NCAP Performance	Performance in Actual Crashes: N of Crashes	Performance in Actual Crashes: Fatality Reduction for Good Car (%)
Chest g's ≤ 56	Chest g's > 56	125	19*
HIC ≤ 1000	HIC > 1200	113	14*
L Femur ≤ 1600 AND R Femur ≤ 1600 AND L+R Femur ≤ 2600	L Femur > 1600 OR R Femur > 1600 OR L+R Femur > 2600	132	20**
HIC ≤ 1100 AND Chest g's ≤ 60	HIC > 1300 OR Chest g's > 60	125	19*
Chest g's ≤ 56 AND L Femur ≤ 1400 AND R Femur ≤ 1400 AND L+R Femur ≤ 2400	Chest g's > 60 OR L Femur > 1700 OR R Femur > 1700 OR L+R Femur > 2700	134	22**
HIC ≤ 900 AND L Femur ≤ 1400 AND R Femur ≤ 1400 AND L+R Femur ≤ 2400	HIC > 1300 OR L Femur > 1700 OR R Femur > 1700 OR L+R Femur > 2700	121	19*
HIC ≤ 900 AND Chest g's ≤ 56 AND L Femur ≤ 1400 AND R Femur ≤ 1400 AND L+R Femur ≤ 2400	HIC > 1300 OR Chest g's > 60 OR L Femur > 1700 OR R Femur > 1700 OR L+R Femur > 2700	118	21**
NCAPINJ ≤ .6	NCAPINJ > .6	117	26**

*Statistically significant at the .05 level
**Statistically significant at the .01 level

A straightforward way to delineate "poor" and "good" scores is to partition the cars based on their NCAP score for a single body region - chest G's, HIC or femur load - and to consider only a subset of the 392 head-on crashes where one car has a score in the "poor" range and the other car has a score in a good or acceptable range. This subset should contain approximately 120 crashes, which is equivalent to defining the worst 20 percent of cars as "poor" performers and the remaining 80 percent as good or acceptable. Do the cars with the poor NCAP scores have significantly more driver fatalities than expected?

When chest G's are used to partition the cars into acceptable and poor performance groups, the cars with high chest G's almost always have significantly more fatalities than the cars with acceptable chest G's.[19] For example, there are 125 actual head-on collisions (both drivers belted) in which one of models had more than 56 chest G's for the driver when it was tested in NCAP, and the other had 56 g's or less. In the 125 cars with chest G's > 56, 80 drivers died, whereas only 68.2 fatalities were expected, based on car weight, driver age and sex. In the 125 cars with chest G's ≤ 56, there were 74 actual and 77.6 expected driver fatalities. That is a statistically significant fatality reduction of

$$1 - [(74/80) / (77.6/68.2)] = 19 \text{ percent}$$

for the cars with the lower chest G's.

The statistical significance of this difference in fatality risk is tested by examining a variable, RELEXP, which is computed for each collision. If E_1 is the expected probability of a fatality in the low-chest G car, based on the formula using car weight, driver age and sex, and E_2 is the expected probability in the high-chest G car, while A_1 and A_2 are the actual outcome in each car (1 if the driver died, 0 if the driver survived),

$$\text{RELEXP} = (A_1 - E_1) - (A_2 - E_2)$$

measures actual performance "relative to expectations." It can range from -2 to +2. The more negative it is, the better the low-chest G car did, relative to expectations. If both groups of cars were equally safe, the average value of RELEXP should be close to zero. But in these 125 crashes, the average value of RELEXP is significantly less than zero ($t = 2.32$, $p < .05$), which means that the fatality reduction for the low-chest G cars is statistically significant.[20]

The relationship between chest G's on the NCAP test and fatality risk over the range of head-on collisions experienced on the highway, although statistically significant, is not perfect. Merely having the lower NCAP score of the two cars in the collision does not guarantee survival, even if the two cars are of the same weight and the drivers of the same age and sex. Yet, on the average, in collisions between cars with ≤ 56 chest G's on NCAP and cars with > 56 chest G's, the driver of the car with the better NCAP score had 19 percent less fatality risk than the driver of the car with the poorer NCAP score, after controlling for weight, age and sex.

Fifty-six chest G's are just one possible boundary value between "good" and "poor" performance. The fatality reduction for "good" performers can be magnified by using a higher boundary value or by replacing a single boundary value with a gap, putting some distance between the "good" and the "poor" groups. For example, in collisions of cars with chest G's ≤ 60 into cars with chest G's > 60 (the pass-fail criterion in FMVSS 208), the fatality reduction in the "good" performers is 24 percent. However, there are only 92 crashes meeting those criteria. Many other boundary values between low and high chest G's will also produce statistically significant fatality reductions for the group with low chest G's, but the boundary value of 56 maximizes the fatality reduction for an accident sample close to 120 crashes.

The Head Injury Criterion (HIC) can be used to partition the cars into two performance groups. In 113 head-on collisions between a car with HIC ≤ 1000 on the NCAP test and a car with HIC > 1200, the fatality risk was a statistically significant 14 percent lower in the cars with HIC ≤ 1000. The femur loads measured on the NCAP tests can also, by themselves, differentiate safer from less safe cars. The "good" performers are defined to be the cars with ≤ 1600 pounds on each leg, and the sum of the two loads ≤

2600 pounds. The "poor" performers are those with > 1600 pounds on <u>either</u> leg, <u>or</u> a sum > 2600 pounds. In 132 head-on collisions, the fatality reduction for the "good" NCAP femur load performers was a statistically significant 20 percent.[21]

One reason that chest G's, HIC and femur load all "work" by themselves is that the three NCAP test measurements are not independent observations on isolated body regions. Cars with intuitively excellent safety design tend to have low scores on all parameters, while cars with crashworthiness problems tend to have high scores on one or more parameters, but it is not always predictable which one. Still, the reasons for the significant correlation between NCAP femur load and actual fatality risk are not completely understood at this time, since injuries to the lower extremities, by themselves, are generally not fatal.

Any two NCAP parameters, working together, can do an even more reliable job than any single parameter. In 125 actual head-on collisions between cars with driver HIC ≤ 1100 <u>and</u> chest G's ≤ 60 on the NCAP test and cars with either HIC > 1300 <u>or</u> chest G's > 60, the fatality risk was a statistically significant 19 percent lower in the cars with low HIC and chest G's. Table 3 shows how chest G's and femur load, or HIC and femur load can be used to partition the cars, with statistically significant 19-22 percent fatality reductions for the "good" performers, in samples of 121-134 crashes.[22]

NHTSA's Report to Congress highlighted three analyses in which cars were partitioned into good and poor performance groups according to the HIC and chest G's.[2] In Case I, the "good" car has to meet the FMVSS 208 criteria (HIC ≤ 1000 and chest G's ≤ 60) while the "poor" car has to fail at least one criterion (HIC > 1000 or chest G's > 60). Cases II and III place a gap between "good" and "poor" performance. In Case II, the "good" car has to meet the FMVSS 208 criteria for HIC and chest G's while the "poor" car has to have HIC > 1200 or chest G's > 70. In Case III, the "good" car must have HIC ≤ 900 and chest G's ≤ 56, while the poor car has HIC > 1250 or chest G's > 65. (These three cases are of particular interest because they were used in a parallel analysis of fixed-object impacts, that is summarized in the next section of this paper.) Table 4 shows the actual and expected fatalities in the three cases, as well as the average vehicle weight and driver age. The "unadjusted fatality reduction" (simple difference of actual fatalities in the "good" vs. the "poor" cars) is 20 percent in Case I, 30 percent in Case II and 33 percent in Case III. After adjusting for car weight, driver age and sex, the fatality reductions are 14, 19 and 27 percent, respectively. The adjusted fatality reductions are not too much smaller than the unadjusted reductions, because in these particular analyses, the "good" cars have a modest weight advantage over the "poor" cars, as shown in Table 4, but the advantage is partly offset because the drivers are slightly younger in the "poor" cars.

Table 4

Collisions of Cars with "Good" NCAP HIC and Chest G's into Cars with "Poor" HIC or Chest G's

	CASE I	CASE II	CASE III
Definition of "good" car: HIC ≤	1000	1000	900
AND Chest G's ≤	60	60	56
Definition of "poor" car: HIC >	1000	1200	1250
OR Chest G's >	60	70	65
Average car weight:			
"Good" cars	2920	2941	2944
"Poor" cars	2769	2769	2761
Average driver age:			
"Good" cars	43.7	42.2	46.4
"Poor" cars	41.1	41.0	43.5
N of head-on collisions	170	104	81
Actual driver fatalities			
In the "good" cars	89	50	39
In the "poor" cars	111	71	58
Expected driver fatalities			
In the "good" cars	96.2	56.8	45.8
In the "poor" cars	103.8	65.2	49.9
"Unadjusted" fatality reduction for the good cars (%)*	20	30	33
"Adjusted" fatality reduction for the good cars (%)**	14	19	27

*e.g., in Case I, the unadjusted reduction is 1 - (89/111).

**e.g., in Case I, the reduction is 1 - [(89/111) / (96.2/103.8)] after adjusting for car weight, driver age and sex.

NCAP scores for all three body regions, with an independent "pass-fail" criterion on each score, work about as well as scores for any two body regions. "Good" performance could be defined as HIC ≤ 900 <u>and</u> chest G's ≤ 56 <u>and</u> femur load ≤ 1400 on each leg and ≤ 2400, total, while HIC > 1300 <u>or</u> chest G's > 60 <u>or</u> femur load > 1700 on either leg or > 2700, total defines "poor" performance. The fatality risk in 118 actual head-on collisions between a good and a poor NCAP performer is a statistically significant 21 percent lower for the drivers of the cars with good NCAP scores, after controlling for vehicle weight, driver age and sex. These criteria can be varied by a moderate amount and the fatality reduction for the "good" performers will still be statistically significant, as long as the HIC cutoff is reasonably close to or slightly above the FMVSS 208 value of 1000, the chest G cutoff is not far from the FMVSS 208 value of 60 g's, and the femur load cutoff ranges from about 1400 pounds up to the FMVSS 208 value of 2250 pounds.[23]

A highly efficient way to use the NCAP scores for the three body regions, however, is to combine them into a single composite score, wherein excellent performance on two body regions might compensate for moderately poor performance on the third. The composite score could be some type of weighted or unweighted average of the scores for the various body regions. For example, a weighted average measure of NCAP performance, NCAPINJ, was derived by a two-step process. First, the actual NCAP results for the driver dummy were transformed to logistic injury probabilities, HEADINJ, CHESTINJ, LFEMURINJ and RFEMURINJ, each ranging from 0 to 1.[24] The weighted average

$$\text{NCAPINJ} = .21\ \text{HEADINJ} + 2.7\ \text{CHESTINJ} + 1.5\ (\text{LFEMURINJ} + \text{RFEMURINJ})$$

has the empirically strongest relationship with fatality risk for belted drivers in the specific data set of actual head-on collisions described above (396 collisions, 792 cars). The accident data include 117 head-on collisions of a car with NCAPINJ $\leq$ 0.6 into a car with NCAPINJ $>$ 0.6. Fatality risk is a statistically significant 26 percent lower in the cars with NCAPINJ $\leq$ 0.6 (t for RELEXP is 3.22, $p < .01$). Since NCAPINJ is a weighted sum of NCAP scores for all of the body regions, the cars with NCAPINJ $\leq$ 0.6 have, on the average, substantially lower HIC, chest G's and femur loads than cars with NCAPINJ $>$ 0.6.[25]

The statistically significant relationship between NCAP performance and actual fatality risk is not limited to head-on collisions in which one vehicle is specifically a "good" performer and the other has "poor" NCAP scores. There is also a strong relationship in the full data set of 392 head-on collisions, which includes crashes between two "good" performers or two "poor" performers. NCAPINJ was defined in a way that makes it easy to test if it is correlated with fatality risk. DELNCAP = $\text{NCAPINJ}_1 - \text{NCAPINJ}_2$, the relative NCAP score for the two vehicles in the crash, and RELEXP, the measure of actual fatality risk defined above, have a correlation coefficient of .166, which is significant at the .001 level in a sample of 392 crashes. In other words, the higher the NCAP score for car 1 relative to car 2, the higher the fatality risk for driver 1 relative to driver 2, after adjusting for car weight, driver age and sex.[26]

The purpose of defining NCAPINJ was to illustrate the strength of the overall relationship between NCAP performance and fatality risk. However, NCAPINJ is not a "magic bullet" or "ideal" way to combine the NCAP scores, resulting in far higher correlations than other methods. Many other weighted averages, or even an unweighted sum of the logistic injury probabilities, work almost as well for differentiating the safer from the less safe cars on the principal accident data set. On a more restricted alternative accident data set of 310 collisions and 620 cars, where the FARS vehicles are also required to have the same number of doors as their matching NCAP test vehicles, NCAPINJ is not the optimum weighted average (although it comes close to the optimum), and it is only slightly more correlated with fatality risk than an unweighted sum of the logistic injury probabilities. Moreover, on this alternative data set, HIC and femur load have about equally strong correlation with fatality risk.[27]

Improvements in Actual Crashworthiness and NCAP Performance during 1979-91

It was shown above that the performance of passenger cars on the NCAP test has greatly improved since the program was initiated in 1979. Has the historical trend of better performance on the NCAP test been matched by a reduction in the actual fatality risk of belted drivers in head-on collisions?

In general, it is not easy to compare the crashworthiness of cars of different model years. Fatality rates per 100 million vehicle miles have been declining for a long time. In any given year, the fatality rate per 100 million miles or per 100 crashes is lower for new cars than for old cars. Both trends create the impression that "cars are getting safer all the time," but, in fact, the declines in fatality rates to a large extent reflect changes in driving behavior, roadway environments, demographics or accident-reporting practices. A head-on collision between cars of two different model years, however, reveals their relative crashworthiness. Both cars are in essentially the same frontal collision, on the same road, in the same year, on the same accident report. The behavior of each driver, prior to the impact, has little effect on who dies during the impact. After adjustment for differences in car weight, driver age and sex, the model year with more survivors is more crashworthy. For example, a similar analysis of head-on collisions involving two unrestrained drivers found little change in fatality risk between model years 1970 and 1984.[28]

There have been 241 actual head-on collisions between a model year 1979-82 car and a model year 1983-91 car, in which both drivers were belted. These collisions allow a comparison of cars built during the first four years of NCAP to subsequent cars, where manufacturers have had time to build in safety improvements. In the 241 older cars, 146 drivers died, whereas only 126.6 fatalities were expected, based on car weight, driver age and sex. In the newer cars, there were 132 actual and 147.1 expected driver fatalities. For the 1983-91 cars, that is a fatality reduction of

$$1 - [(132/146) / (147.1/126.6)] = 22 \text{ percent}$$

and it is statistically significant (t for RELEXP is 3.43, $p < .01$).[29]

A more generalized analysis, which allows a larger sample size of 1189 crashes, applies to head-on collisions in which the "case" vehicle of interest is a 1979-91 car that matches up with an NCAP test, whose driver wore belts, but the "other" vehicle in the crash can be any 1976-91 passenger car with a belted driver. For any subset of crashes, the actual fatalities are tallied in the "case" and "other" vehicles, and so are the expected fatalities (based on the relative weights of the two cars, and the age and sex of the two drivers). The fatality risk index for the "case" vehicles is

$$100\ [(\text{actual}_{\text{case}} / \text{actual}_{\text{other}}) / (\text{expected}_{\text{case}} / \text{expected}_{\text{other}})]$$

The lower the risk index, the more crashworthy the car (100 = average). The actual fatality risk indices can be compared in three model-year groups, 1979-82, 1983-86 and 1987-91. So can the NCAP test performance, as measured by a composite score such as NCAPINJ, by the average values of the actual NCAP parameters for the three body regions, or by the average value of the joint probability of AIS $\geq$ 4 injury to the head or chest:

	Model Years		
	1979-82	1983-86	1987-91
Fatality risk index in actual head-on collisions	119	95	91
Average value of NCAPINJ	.59	.40	.37
Percent of cars with NCAPINJ > 0.6	49	14	9
Average HIC	1052	915	827
Average chest G's	54.9	46.8	46.5
Joint head-chest injury probability	.32	.25	.22
Average left femur load	928	883	1002
Average right femur load	1079	784	1018

The trends in the actual fatality risk and the average value of NCAPINJ are almost identical. The risk index decreased by a statistically significant 20 percent from 1979-82 to 1983-86, and by another 4 percent from then until 1987-91 (nonsignificant). In all, the actual fatality risk for belted drivers in head-on collisions decreased by a statistically significant 24 percent from model years 1979-82 to 1987-91. A composite NCAP score, such as NCAPINJ, nicely portrays the improvement in NCAP performance over time. Parallel to the reduction in the fatality risk index, NCAPINJ greatly improved from an average of 0.59 in model years 1979-82 to 0.40 in 1983-86, with an additional, modest improvement to 0.37 in 1987-91. If NCAPINJ = 0.6 is defined as the limit of "acceptable" NCAP performance, the passenger car fleet has truly progressed since the inception of NCAP: initially, 49 percent of the cars had NCAPINJ > 0.6, but that decreased to 14 percent in 1983-86 and 9 percent in 1987-91. Average HIC and chest G's declined substantially during the NCAP era; average femur loads stayed about the same, but well below the 2250 pounds permitted in FMVSS 208.[30]

A final question is whether the correlation of actual fatality risk with NCAP performance is merely a coincidence, in the sense that fatality risk and NCAP scores both decreased during model years 1979-91, and thus became correlated with one another just because both are correlated with model year. The earlier analysis of collisions of cars with NCAPINJ $\leq$ .6 into cars with NCAPINJ > .6 was rerun, limited to crashes in which the "good" and the "poor" NCAP performers had similar model years ($-5 \leq MY_{GOOD} - MY_{POOR} \leq 3$). In these 61 crashes, where the average model year for the "good" and "poor" NCAP performers was equal, and the average car weight, driver age and sex nearly equal, the fatality risk was a statistically significant 32 percent lower in the "good" NCAP performers than in the poor performers (t for RELEXP is 3.03, $p < .01$). This result and other, similar analyses confirm that the strong association between NCAP performance and actual fatality risk in head-on collisions is quite independent of model year.[31]

Principal Findings, Conclusions and Caveats for the Analysis of Fatality Risk in Head-On Collisions

- There is a statistically significant correlation between the performance of passenger cars on the NCAP test and the fatality risk of belted drivers in actual head-on collisions. Since many head-on collisions differ substantially from NCAP test conditions, this suggests NCAP scores are correlated with actual crashworthiness in a wide range of crashes.
- In a head-on collision between a car with "acceptable" NCAP performance and a car of equal mass with "poor" performance, the driver of the "good" car has, on the average, about 15-25 percent lower fatality risk.
- A highly effective way to differentiate "good" from "poor" NCAP performance is by a single, composite NCAP score, such as a weighted combination of the scores for the three body regions. However, even the NCAP score for any single body region can be used to partition the fleet so that the cars with "good" scores have significantly lower fatality risk than the cars with "poor" scores. The borderline between "good" and "poor" NCAP scores that optimizes the differences in actual fatality risk is close to the FMVSS 208 criteria for each of the three body regions.
- NCAP scores have improved steadily since the inception of the program in 1979, with the greatest improvement in the early years. By now, most passenger cars meet the FMVSS 208 criteria in the 35 mph NCAP test. This achievement has been paralleled by a 20-25 percent reduction of fatality risk for belted drivers in actual head-on collisions in model years 1979-91, with the largest decreases during the early 1980's.
- This is a statistical study and it is not appropriate for conclusions about cause and effect. It shows that passenger cars became significantly safer in head-on collisions during 1979-91, as NCAP scores improved. It does not prove that the NCAP program was the stimulus for each of the vehicle modifications that saved lives during 1979-91. (For example, the automatic protection requirement of FMVSS 208 was another important stimulus.)
- The correlation between NCAP scores and actual fatality risk is statistically significant, but it is far from perfect. On the whole, cars with poor NCAP scores have higher-than-average fatality risk in head-on collisions, but there is no guarantee that every specific make-model with poor NCAP scores necessarily has higher fatality risk than the average car. Conversely, there is no guarantee that a specific model with average or even excellent scores necessarily has average or lower-than-average fatality risk in head-on collisions.
- The data show that cars with poor NCAP scores (e.g., above the FMVSS 208 criteria) have significantly elevated fatality risk in head-on collisions, but they do not show a significant difference between the fatality risk of cars with exceptionally good NCAP performance and those with merely average performance.

ANALYSIS OF FATAL CAR-TO-FIXED OBJECT FRONTAL COLLISIONS

Concurrent with the analysis of head-on collisions, a more generalized study of FARS was conducted to determine if cars with "good" NCAP scores also had lower-than-average fatality risk in frontal crashes other than the car-to-car head-on collisions. In this analysis, the fatality rate for restrained drivers in frontal fixed-object collisions, per million vehicle years, was compared for cars with "good" NCAP scores and cars with poor scores.

The study is based on 1979-90 FARS data on MY 1979-90 passenger cars.[10] The first step in the analysis was to identify the cars in FARS for which NCAP test results were available. The make-model and number of doors had to match exactly in FARS and NCAP. The model years of the FARS and NCAP could be identical, or the FARS model year could be later than the NCAP model year, if that make-model was basically unchanged during the intervening years.[32] For these applicable vehicles, records of restrained drivers killed in single-vehicle frontal, fixed-object collisions were extracted from FARS. Exposure data (vehicle registration years) were obtained from R. L. Polk's National Vehicle Population Profile.[15] The number of exposure years from the Polk file was multiplied by the on-the-road belt use rate for drivers,[33] to obtain the "restrained exposure years." The frontal, fixed-object fatality rates per million exposure years (for restrained drivers) was computed and compared for cars with good and poor NCAP performance, where the definitions of "good" and "poor" are based on HIC and chest G's, as in Case I, Case II and Case III of Table 4.

In Case I, the "good" car has to meet the FMVSS 208 criteria (HIC $\leq$ 1000 and chest G's $\leq$ 60) while the "poor" car has to fail at least one criterion (HIC > 1000 or chest G's > 60). Cases II and III place a gap between "good" and "poor" performance. In Case II, the "good" car has to meet the FMVSS 208 criteria for HIC and chest G's while the "poor" car has to have HIC > 1200 or chest G's > 70. In Case III, the "good" car must have HIC $\leq$ 900 and chest G's $\leq$ 56, while the poor car has HIC > 1250 or chest G's > 65.

The results for frontal, fixed-object crashes are shown in Table 5 along with the average vehicle test weight, drivers' HICs, and drivers' chest G's from NCAP. The last row of Table 5 shows the reduction in the fatality rate, for "good" relative to "poor" NCAP performers. The fatality reduction for good NCAP performance is 19 percent in Case I, 22 percent in Case II and 36 percent in Case III. Unlike the analysis of head-on collisions, the fatality rates here have not been adjusted for differences in car weight, driver age or sex. Also unlike the head-on collisions, these data do not "self-adjust" for differences in crash-involvement propensities. Nevertheless, as was noted in Table 4, there is, on the average, little difference in the vehicle weights and driver ages of "good" and "poor" NCAP performers. In the analyses of head-on collisions in Table 4, both "adjusted" and "unadjusted" fatality reductions were computed for the good NCAP performers, and they were not too far apart. The fatality reductions in Table 5 must be compared to the "unadjusted" reductions in Table 4.

Table 5

Summary of Real-World NCAP Effects Based on FARS Analysis of Car-to-Fixed Object Frontal Collisions

Parameter	Group No.	Case I*	Case II*	Case III*
Average vehicle NCAP test weight	1	3183	3183	3150
	2	3197	3180	3202
Average drivers' HIC from NCAP	1	722	722	676
	2	1315	1614	1435
Average drivers' chest G's from NCAP	1	45	45	44
	2	58	58	62
Reduction in fatality rate - cars in group 1 vs. cars in group 2 - actual FARS data		19.2 %	21.8 %	35.7 %

*Case I - Cars in Group 1 have HIC values $\leq$ 1000 and chest G's $\leq$ 60 in the NCAP tests. Cars in Group 2 have HIC > 1000 and/or chest G's > 60 in the NCAP tests.

*Case II - Cars in Group 1 have HIC values $\leq$ 1000 and chest G's $\leq$ 60 in the NCAP tests. Cars in Group 2 have HIC > 1200 and/or chest G's > 70 in the NCAP tests.

*Case III - Cars in Group 1 have HIC values $\leq$ 900 and chest G's $\leq$ 56 in the NCAP tests. Cars in Group 2 have HIC > 1250 and/or chest G's > 62 in the NCAP tests.

Figure 7 reveals remarkable similarity in the results for head-on and fixed-object collisions. In Case I, the unadjusted fatality reduction for the good NCAP performers was 20 percent in the head-on collisions and 19 percent in the fixed-object impacts. In Case II, the reductions were 30 and 22 percent. In Case III, where the definitions of a "good" and a "poor" car straddled the FMVSS 208 criteria and produce the largest relative fatality reduction, that reduction is 33 percent in the head-on collisions and 36 percent in the fixed-object crashes. NHTSA is contemplating more detailed analyses of single vehicle crashes, including methods to control for driver age, etc., and to test the statistical significance of differences in fatality rates.[34] For now, these initial analyses show consistency with the results in head-on collisions and suggest that the findings in car-to-car head-on crashes may also be applicable to these other frontal crashes.

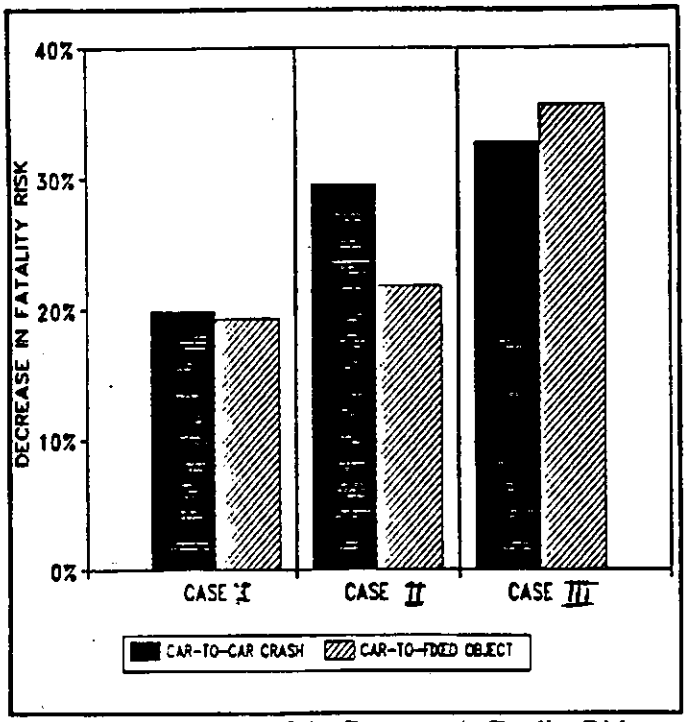

Figure 7. Comparison of the Decrease in Fatality Risks for "Good" Performing Cars in NCAP in Car-to-Car and Car-to-Fixed Object Collisions

THE FUTURE FOR NCAP

Make NCAP Easy to Understand

NCAP has produced extensive frontal crash test information for use by consumers and the media. However, as noted in NHTSA's Focus Group Study and Media Survey, this information has been difficult for some consumers to understand and the media to use.[35] NHTSA's first step toward the goal of reaching a larger group of the population has been to simplify the data in order to assist consumers in making their vehicle purchase decision.[36]

The primary element for Fiscal Year 1994 will be a consumer brochure in a computerized format. This will permit easy updating. The format will also be adaptable to print media requirements. The brochure will utilize an easy to read and simple presentation technique. It will contain a description of NCAP and the comparative results from the vehicle tests.

Expand the Usefulness of NCAP

NCAP has evolved into a real catalyst in the automobile market place. Consumer enlightening publications highlight crash test results as an important ingredient to consider in the vehicle selection process. As explained at the beginning of this paper, the overall trend of the NCAP test results indicate the favorable influence the program has had on motivating the manufacturers to improve restraint systems, steering assemblies, and structural crash characteristics of many of their products. The accident analyses highlighted the significance of these improvements as shown, statistically, in the reduction of fatality risks for restrained occupants in the "good" performing passenger cars. In addition, NCAP continues to be a main source of research and engineering data for use by NHTSA and others in directing research programs and analyzing safety problems. With the exclusive use of the Hybrid III dummy in the NCAP frontal tests, NHTSA will expand the collection of safety information by utilizing the additional capabilities of the more advanced dummy to measure the potential for lower limb and neck injuries. From these perspectives, the frontal crash testing of NCAP has been and continues to be successful.

The focus group recommendations critically pointed out that NCAP provides information for frontal crashes only. Although the frontal crashes account for the highest percentage of fatalities, as shown in Figure 8, side crashes and rollovers are also very prominent crash modes. Almost 8,000 fatalities occurred in side crashes in 1991 and more than 9,000 fatalities occurred in rollover crashes. The focus group study indicates that consumers desire overall safety information on vehicles. In essence, NHTSA needs to expand the crash modes covered by NCAP.

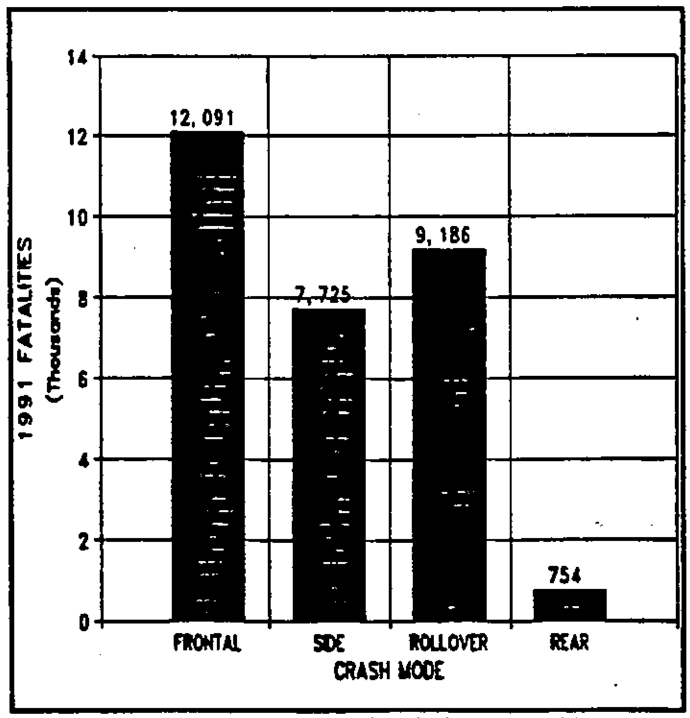

Figure 8. 1991 Fatalities occurring in Frontal, Side, Rollover, and Rear Crash Modes - Passenger Cars and Light Trucks.

The enactment of the upgraded side-impact protection standard, beginning with MY 1994 passenger cars, has provided the opportunity to expand NCAP into side-impact protection.[37] The expansion of NCAP into side-impact protection has the potential for improving occupant protection well above that required in the applicable standard if the vehicle manufacturers, which have been responsive to the frontal NCAP test results, are equally responsive to such a program in side-impact testing. As in the frontal NCAP, a side-impact NCAP would provide an engineering data base which can be used to inform consumers of relative vehicle crashworthiness performance. That data base can also serve as a basis for further research and additional studies in side-impact.

Side Impact NCAP

In Fiscal Years 1992 and 1993, Congress provided funds as requested by NHTSA to conduct a study to develop the requirements and procedures for the possible expansion of NCAP into side-impact protection. This two-year study included a pilot crash testing program to determine an NCAP crash severity level, to assure that testing, instrumentation, and test device performance are consistent. The results from this program support the feasibility of a side-impact NCAP which could provide comparative results to consumers. If Congressional funding is provided, side-impact NCAP tests would be conducted on passenger cars and the information would be provided to consumers along with the frontal NCAP information. Initiation of this side-impact NCAP would provide consumers with comparative safety data on two of the most important crash modes.

Rollover Testing

Research efforts continue in NHTSA to determine the feasibility of determining vehicle crashworthiness performance in the rollover crash mode. These efforts have focussed on evaluating vehicle structural integrity and restraint system effectiveness during dynamic rollover events. Advanced mathematical modelling techniques have been developed and applied, rollover test devices have been constructed, and several demonstration rollover tests have been conducted. NHTSA will continue to monitor these activities to determine the potential for providing consumers with comparative safety information on levels of protection in the rollover crash mode.

In addition to these crashworthiness rollover activities, NHTSA continues to study the merits of providing consumers with information on the roll stability of passenger cars and light trucks, vans, and sports utility vehicles. NHTSA published an Advance Notice of Proposed Rulemaking on January 3, 1992[38] and a Planning Document for Rollover Prevention and Injury Mitigation on September 23, 1992.[39] In these documents, potential methods for developing and providing consumer information are discussed. Comments to these documents are being reviewed by NHTSA.

In Conclusion

The future for NCAP includes several major goals:

- Reach a larger group of the population with simplified data that will assist consumers in their vehicle purchases,
- Expand the collection of safety information by utilizing the additional capabilities of the more advanced Hybrid III dummy to measure the potential for lower limb and neck injuries,
- Expand NCAP into side-impact testing to provide comparative side impact information to consumers along with the frontal NCAP information, and
- Monitor rollover safety activities to determine the potential for providing consumers with comparative information on levels of protection in the rollover crash mode and on vehicle roll stability.

Next Steps

NHTSA is considering holding a public meeting on NCAP. The public meeting could provide an open forum for consumer groups, media, foreign governments, national and international safety organizations, and motor vehicle manufacturers to discuss the above NCAP goals. A *Federal Register* notice was issued on January 4, 1994, requesting comments on the possibility of convening such a meeting and on the scope of materials which might be discussed; NHTSA has received the comments and is reviewing them.[40]

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22) Ibid., pp. 98-103.
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HEADINJ = 1 / [1 + exp(5.02 - .00351 HIC)]
CHESTINJ = 1 / [1 + exp(5.55 - .06930 chest g's)]
LFEMURINJ = 1 / [1 + exp(7.59 - .00294 left femur load)]
RFEMURINJ = 1 / [1 + exp(7.59 - .00294 right femur load)]

They measure the probability of AIS $\geq$ 4 head and chest injury and AIS $\geq$ 3 leg injury, as a function of HIC, chest g's and femur load. They are based on research in Prasad, Priyaranjan, and Mertz, Harold J., *The Position of the United States Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment*, SAE Paper No. 851246, Society of Automotive Engineers, Warrendale, PA, 1985; and Viano, David C., and Arepally, Sudhakar, *Assessing the Safety Performance of Occupant Restraint Systems*, Report No. GMR-7093, General Motors Research Laboratories, Warren, MI, 1990.
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30) Ibid., pp. 135-142. The joint probability of AIS $\geq$ 4 head or chest injury is 1 - [(1 - HEADINJ)(1 - CHESTINJ)], where HEADINJ and CHESTINJ are the logistic injury probability functions defined from HIC and chest G's in footnote 24.
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