THE SAFE ROAD TO FUEL ECONOMY

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Executive Summary

INTRODUCTION

Since 1974, new car fuel economy has increased by 100% and traffic fatalities have decreased by 40%. (Figures 1 & 2.) In 1991, we save 2.5 million barrels per day of gasoline and 30,000 lives annually due to improved CAFE and decreased fatality rates over the past 17 years. This study demonstrates that as we look forward to the year 2001, we can continue to improve both CAFE and vehicle safety. By implementing the vehicle safety and fuel economy proposals set forth in this study, we can attain CAFE levels of 40-45 MPG and reduce vehicle fatalities to 1.6 per 100 million vehicles miles travelled (VMT) by 2001. Compared to the 1974 CAFE levels of 14 MPG and fatality rate of 3.5 per 100 million VMT, we would save over 5 million barrels per day of gasoline and 50,000 lives per year.

Of the 13.8 MPG gain in CAFE from 14 MPG in 1974 to 27.8 MPG in 1991, 11.8 MPG or 86% results from technological improvements to passenger cars. The increase in CAFE due to weight loss from 1974 was only 1.8 MPG or 13.1%. And the improvement due to a shift to smaller cars was only 0.2 MPG or 1.4%. The 13.8 MPG improvement since 1974 is all the more remarkable because we lost 2.5 MPG due to tuning engines for faster acceleration times between 1981 and 1991. If we had traded out engine performance improvements for CAFE gains instead of faster acceleration, we would have had a 1991 CAFE of 30.3 MPG and a gain of 16.3 MPG with 14.3 MPG or 88% coming from technological improvements.

PHASE-OUT OF UNSAFE, FUEL INEFFICIENT CARS

When Congress passed the CAFE law, it forced the car companies to phase out older, less fuel efficient vehicles which were also unsafe. While many of the replacement vehicles had major advances in fuel efficiency, most had only moderate improvements in safety and none utilized the advanced safety features available to the manufacturers and discussed in this study. As examples, the study cited six models which were replaced in the late 1970's and early to mid-1980's where the vehicles improved in gas mileage and safety as shown by their lower death rates per 100 million VMT and crash-worthiness as measured in NHTSA's 35 MPH crash tests. (Table 1.)

In each case, the CAFE of the replacement vehicle went up by 5-20% while the fatality rate went down by 30-50%. One of the best examples of combined improvement in gas mileage and safety is the replacement of the VW Beetle by the VW Rabbit. The Rabbit was a lighter vehicle with a shorter wheelbase yet had a 44% drop in death rate and a 25% improvement in gas mileage from 26.0 to 32.6 MPG. When Honda replaced the 1800 pound Civic in 1981, its gas mileage went from 33.5 to 37.8 MPG and its fatality rate also dropped by 44%. The virtual elimination of the mini-compact car which went from 11.4% of the market in 1974 to 0.8% in 1990 shows that tighter CAFE standards does not necessitate small cars.

BASIC SAFETY IMPROVEMENTS

Since the Highway Safety Act of 1966 the fatality rate for all vehicles has declined over 50% while fuel economy has doubled. Recent contributions to improvements in vehicle safety include the greater use of available restraints, particularly in small cars, the greater number of mid-size cars, the 1977 to 1986 reduction in the number and weight of large cars and the introduction of "passive (padded) interiors." Based on where we are today, only a virtually impossible production mix of vehicles, combined with an irrational disregard for safety considerations which is not in evidence, could reverse and adversely effect the gains in safety of the past twenty years.

For a given population of cars there is no relationship between CAFE and current levels of Safety. The safety of vehicles has been demonstrated to be easily improved from current levels with significant weight reductions. Safety is related to structural crashworthiness and occupant protection design alternatives, while fuel economy is related to engine and transmission efficiency, power to weight ratio, acceleration performance, drag coefficient and vehicle size (which has weight implications).

ADVANCED SAFETY AND FUEL ECONOMY FOR 1996 AND 2001

Based on industry and government research and development test data, known technology and available design alternatives including those developed in the Department of Transportation's Research Safety Vehicle (RSV) program, the study assessed and determined that the following safety and fuel economy goals could be met, if not exceeded, by 1996 and 2001.

Safety 1996: Modify FMVSS 208 to substitute 35 mph frontal and 45° angled barrier test and implement a rollover test with (4000 newton) neck compression injury criteria.

Fuel Economy 1996: Achieve 35 MPG CAFE simultaneous with Safety improvements.

Safety 2001: Raise the FMVSS 208 frontal and angled safety protection performance to 40 mph and conduct all FMVSS 214 Side Impact tests at the same speed.

Fuel Economy 2001: Achieve 40 MPG CAFE simultaneous with Safety improvements.

1996 ANALYSIS

The analysis assumed there would no shift to smaller cars from the present 1990 mix of vehicles in the fleet. The analysis selected a typical car in each size category and estimated the effect on weight of modest design and engine changes which could be accomplished in the near term. (Table 3.) The estimates are backed up by at least one current production car which is just a "near-best-in-class" to permit a wider choice of vehicles.

The choices were made to achieve the required performance with the least leadtime, structural modifications, weight penalty and change in current or planned product technology. By size class, this means the following changes:

Large - slightly improved roof strength, upper structure passive interior, laminated side glazing, the already included SRS AirBags, ABS and Contoured side impact padding.

Midsize - slightly improved roof strength, upper structure passive interior, laminated side glazing, the already included SRS AirBags, ABS and Contoured side impact padding.

Compact - improved roof strength, HSLA fender wells and catwalks, upper structure passive interior, laminated size glazing, uploading and compartmenting the driver side SRS AirBags on a stroking RSV steering column, advanced airbag on passenger side, ABS and Contoured side impact padding.

Subcompact - improved roof and A pillar strength, HSLA fender wells and catwalks, improved door beam hinge and latch attaches, upper structure passive interior, laminated side glazing, uploading and compartmenting the driver side SRS AirBags on a stroking RSV steering column, advanced airbag on passenger side, ABS and Contoured side impact padding.

For each size car, the choice is for Four cylinder, sequential fuel injected, multi-ported, Transverse, Front Wheel drive with electronically shifted five speed transmission. Application of just a near-best-in-class choice results in a 36.0 MPG CAFE. As shown in the following table, it is within current technology to achieve the desired 1996 safety and fuel economy performance goals.

Typical Size Compartment	EPA/ORIG. avg. mpg	Redesign mpg	%Share	ENG/TRNS Basis
Large	23.8	28.0	13.3%	SAAB 9000S
Midsize	26.2	32.2	27.6%	Chev. Corsica
Compact	28.9	40.7	31.3%	Pontiac LeMans
Subcompact	31.6	40.9	27.8%	Honda Civic
Average all cars	27.8	36.0	100%	36.0/27.8 = 129%

Analysis of 1990 CAFE data confirms that obtaining a 34 MPH CAFE for 1996 is feasible with present technology and vehicles. The 1990 fleet mix by weight is shown in the table below. If every vehicle in the class was as fuel efficient as the best vehicle in the class, the 1990 CAFE would have been 34.4 MPG versus the 27.8 MPG actually obtained. Since this is a fixed mix and weight scenario by definition, no downsizing or weight reduction has to be done to obtain this CAFE. Present vehicles in every size and weight class already exist to demonstrate the feasibility of meeting 34 MPG by 1996.

1990 Best In Weight Class 34.4 MPG Analysis

Class	1750	2000	2250	2500	2750	3000	3500	4000	4500	5500
Share	0.01	1.3	1.4	12.6	10.4	31.0	31.3	11.0	1.07	0.01
MPG	65.4	56.0	59.2	42.2	46.9	33.2	33.7	25.6	22.9	13.2

2001 ANALYSIS

The Safety situation is much the same for 2001. Most of the higher performance protection will be achieved with upgraded restraint and passive interior components rather than through a change in technology. Weight reductions will be possible through material substitutions and lighter engine/transmissions.

Size Compart	Volume	EPA/1996 Weight	Redesign Weight	Design Changes	Basis
Large	125 cu. ft.	3500#	3250#	MAT'L SUBST.	LRSV
Midsize	115 cu. ft.	3000#	2875#	MAT'L SUBST.	LRSV
Compact	105 cu. ft.	2500#	2500#	HSLA STL	C/C RSV
Subcmpct	90 cu. ft.	2500#	2375#	HSLA STL	CRX

In addition to improvements due to weight reduction, the CAFE improvements will come from engine efficiency efforts and a kind of standardization between car models in the same class on engine/transmission designs, controls and performance exhibited by the best-in-weight-class plus a modest use of new technologies such as further reductions in aerodynamic drag, intake valve control and improved transmissions.

Typical Size Compartment	EPA/ORIG. avg. mpg	Redesign mpg	% Share	ENG/TRNS Basis
Large	23.8	31.3	13.3%	CmryW/Saab9000
Midsize	26.2	35.3	27.6%	EscW /Corsica
Compact	28.9	43.7	31.3%	Ford Escort M4
Subcmpct	31.6	48.8	27.8%	Civic M5/HF
Average all Cars	27.8	40.1	100%	40.1/27.8=144%

As shown in the table above, the advanced safety fleet will obtain 40.1 MPG CAFE in 2001 with just a 3.5% fuel efficiency gain due to new technologies developed and utilized over the next ten years. With many of these technologies such as 5-speed automatic transmissions and intake valve controls, the only issue is not whether they will be used but the extent of their market penetration. Beyond these realized new technologies, auto companies will realize CAFE increases due to alternative fuel vehicles. With maximum utilization of new technologies, including phase-in of direct injection stratified 2-stroke engines in compact cars, the auto companies could attain CAFE levels of 45.8 MPG by 2001.

CONCLUSION

With utilization of the advanced safety and fuel economy technologies discussed above, CAFE levels of 40-45 MPG can be attained by 2001 without any shift to smaller cars. In spite of increased population and vehicle miles travelled, our best projections are that with implementation of current safety regulations as scheduled, by 2001 auto occupant fatalities and injuries will be 10% lower than current levels, but with some continuing disparity between small and large cars and light trucks because NHTSA failed to require advanced safety counter-measures proposed in the 1970's. The FMVSS 208 occupant protection measures proposed in this study would eliminate the disparities between small and large cars, resulting in an additional 10% benefit as shown in the following table. The gasoline savings from a 40% increase in new vehicle fuel efficiency would be 2.8 million barrels per day.

PROJECTED ANNUAL FATALITIES AND INJURIES FROM FMVSS 208 and ADDING FMVSS 214

YEAR	FATALITIES	FAT/100 M VMT		FAT & INJ. in CARS by AIS			
			SER INJ	6	5	4	3
1990	44,500	2.1	394,000	28	36	36	294
1995	42,500	2.0	360,000	26	30	30	274
2000	40,000	1.8	340,000	24	27	28	261

ESTIMATED ANNUAL FATALITIES AND INJURIES FROM PROPOSED CHANGES IN FMVSS 208

2000	36,000	1.6	300,000	22	20	26	232

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ABSTRACT

This paper considers and explains the 1975 projected and 1990 actual Safety and Fuel Economy of Small cars and characterizes for 1996 and 2001 reasonably modified regulations which would result in improvements consistent with industry potential and consumer demands for the safety and fuel economy of various size cars, with practical modifications to current vehicles. An estimate of the resulting reduction of casualties and improvement in fuel economy is provided.

In 1975 NHTSA's Research Safety Vehicle (RSV) Program established the analytical framework for assessing present and future auto safety gains. The 1975 - 1980 Minicars RSV and Large Research Safety Vehicle (LRSV) program established a baseline for quantifying the effects on injuries and fatalities of design alternatives applied to current 1990 cars for future production.

Estimates are coupled with recent and more sophisticated accident data, the results of the later RSV prototype design Phases, published safety studies in the intervening period, recent regulatory implementations, manufacturer's confidential design efforts and production of safety improvements, and some 200 detailed severe injury accident investigations of the past seven years.

The results indicate that with modest, achievable regulatory changes (FMVSS 208 frontal and 45° angled 35 mph barrier impacts, the S8.3 rollover and a 40 MPG CAFE), vehicular fatalities and injuries will continue to decline, the disparity between small and large car and light truck safety can be ameliorated, while manufacturer's simultaneously improve fuel economy 40% by 2001.

INTRODUCTION

The objective of this paper is to provide an engineering basis for understanding the historical trends, current status and future consequences of Safety and CAFE regulations (Figure 1, 2).

It is based on the Background History of Regulation in Safety and CAFE; relevant perceptions of the American consumer and Auto manufacturers; the historical and current accident and injury population and distribution; the available structural, restraint and interior design alternatives and their cost; and the fuel economy by Size class and of current individual Vehicle, Engine and Transmission combinations.

These factors are used to compare the ability to achieve and the consequences of reasonable and consistent Safety and CAFE regulatory goals for 1996 and 2001.

SAFETY BACKGROUND

In 1974, most accidents were between two fairly large cars trying to avoid each other. Of the 125 million vehicles (100 million cars and 25 million trucks) then on our roads, as many as 25 million were involved in 16 million accidents[1], though only 12% wore belts, about two million people were injured. Most were minor injuries, about 101,000 were serious and life threatening, about 30,000 were permanently disabling, and 28,000 died[2]. The Corporate Average Fuel Economy (CAFE) was at about 14 mpg, average new car weight was 3,968 lbs., the average fuel economy of the total on-the-road fleet was about 12 mpg and emissions were well over EPA standards with average lifetime emissions for 1974 models being 4.18 grams/mile for Hydrocarbons, 3.11 for Nitrogen Oxides and 45.49 for Carbon Monoxide.

In 1990, most accidents are between different sized vehicles trying to avoid each other. More than 40% of the occupants of the 190 million vehicles (145 million cars and 45 million trucks) on our roads wear belts, but there are still about two million injured. Again most are minor injuries, but about 210,000 are serious and life threatening, about 70,000 are permanently disabling, and 28,000 die[3]. The CAFE[4] is about 27.8 mpg, average new car weight is 3,178 lbs. and the average fuel economy of the total on-the-road fleet is about 19 mpg and emissions have been greatly reduced by 85% to 0.63 grams/mile for Hydrocarbons, 0.71 for Nitrogen Oxides and 6.88 for Carbon Monoxide for 1991 models.

In 1980 the safety and fuel economy performance of the Minicars Research Safety Vehicle[5] and the Large Research Safety Vehicle were validated by independent tests. Their specifications and those of the Calspan/Chrysler RSV were published by NHTSA in 1978[9]. These vehicles demonstrated what could be achieved, but clearly NHTSA and the Industry on behalf of the Consumer, chose not to require such performance in production during the eighties.

FIGURE 1. U.S. TRAFFIC FATALITY TRENDS 1974-1990

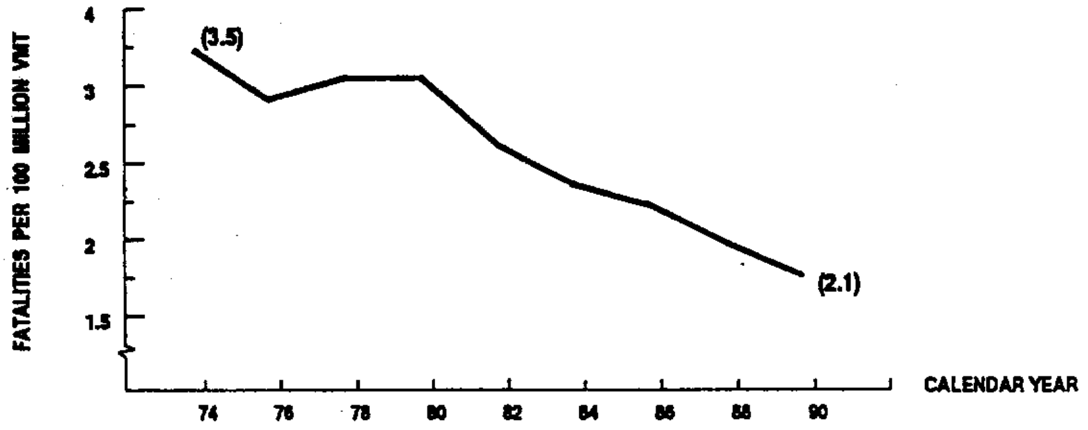
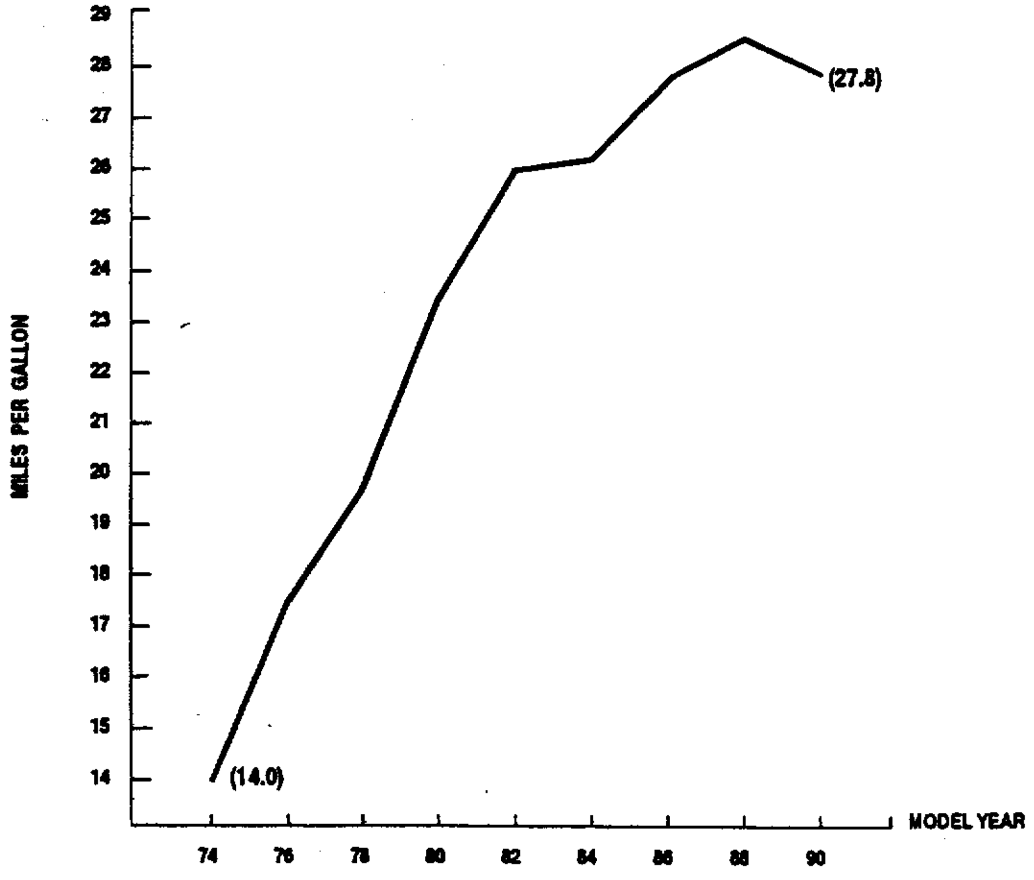


FIGURE 2. AUTO FUEL ECONOMY TRENDS 1974-1990



On the other hand: more than 50% of the vehicles are now small, the percentage of people wearing their belts has increased from 12% to about 47%, the total U.S. population has increased 20%, new safer cars are being added at about 10 million per year and scrapped at about 6 million per year, while trucks are being added at about 4 million and scrapped at about 1.5 million per year, the number of vehicles[6] has increased 50% and the number of people killed per one hundred million miles driven or per vehicle has decreased dramatically.

During the 1970's, Japanese manufacturers, the first major producers of small cars, took advantage of the lack of occupant protection test requirements and U.S. manufacturers used scaled structural designs for their small size cars (like the Chevette), which for a principally unrestrained occupant population, led to the conclusion by the end of that decade that big cars were safer than small ones. The RSV program demonstrated (Figure 3) in 1975, that if the design of cars and use of restraints didn't change, the societal cost of accidents in 1985 would. Fortunately, in the 1980's dynamic tests were mandated, structures were no longer simply scaled, interior occupant protection was enhanced and restraints began to be used.

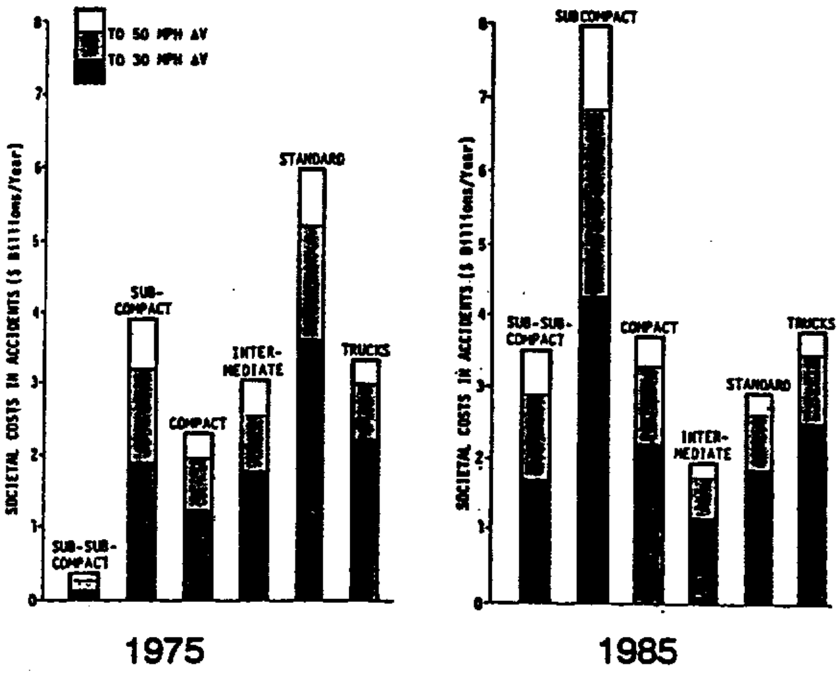


Figure 3. SOCIETAL LOSSES BY VEHICLE SIZE CLASS AND DELTA VELOCITY FOR 1975 AND PROJECTED TO 1985

In 1974, Minicars demonstrated that with a small weight increase and advanced high performance airbags, even the Ford Pinto, could protect occupants to 50 mph[2]. The Escort which advanced safety features available to the manufacturers and discussed in this study. Table 1 lists exemplary models and their replacements in the late 1970's and early to mid-1980's that show these vehicles improved in gas mileage while also making moderate improvements in safety as demonstrated by their lower death rates per 100 million VMT and their crashworthiness as measured in NHTSA's 35 MPH NCAP crash tests[36-42].

TABLE 1. SMALL CAR FATALITY RATES AND NCAP CRASH SCORES BY MANUFACTURER

	CURB WT. Pounds	WHEELBASE Inches	HEAD INJURY Driver/Passenger	DEATHS Per 100MM VMT	CAFE mpg
			Calender Years 1985-89		
HONDA					
1979-80 Civic	1760/1850	87/89	2030/2093 (1979 2D) 2626/1506 (1980 2HB)	2.64	32.4/34.7
1981-82 Civic	2000/1965	91/91	607/ 492 (1981 2HB)	1.47	36.1/39.6
TOYOTA					
1981-82 Tercel	2050/2050	98/98	1218/1179 (1980 2D)	2.32	35.8/35.4
1984-85 Tercel	2145/2145	96/96	658/ 492 (1984 4HB)	1.37	38.7/38.2
1980-81 Corolla	2000/2000	95/95	838/1162 (1980 4D)	2.31	30.4/31.1
1984-85 Tercel	2145/2145	96/96	658/ 492 (1984 4HB)	1.37	38.7/38.2
GENERAL MOTORS					
1984-85 Chevette	2200/2200	97/97	1886/1306 (1984 4HB)	2.46	34.7/35.0
1986-87 Nova	2250/2250	96/96	552/ 562 (1986 4HB)	1.20	36.1/36.1
			Calender Years 1981-82		
VOLKSWAGEN					
1973-74 Beetle	1950/2025	95/95	na	3.79	26.0/26.0
1977-78 Rabbit	1940/1940	94/94	1024/ 429 (1979 2HB)	2.11	32.5/32.8
FORD					
1975-76 Pinto	2590/2570	95/94	na	3.40	26.3/26.3
1981-82 Escort	2050/2090	94/94	618/1011 (1981 2HB)	2.18	32.4/33.8

In each case, the CAFE of the replacement vehicle went up by 5-20% while the fatality rate when down by 30-50%. One of the best examples of combined improvement in gas mileage and safety is the replacement of the VW Beetle by the VW Rabbit. The Rabbit was a lighter vehicle with a shorter wheelbase yet had a 44% drop in death rate and a 25% improvement in gas mileage. The Rabbit's dramatic improvement was due in large part to Volkswagen being one of the few manufacturers to incorporate features from its Experimental Safety Vehicle into production vehicles like the Rabbit.

Structural design to resist intrusion in foreseeable offset and angled impacts and provide protection at frontal injury criteria levels was simply not an objective. Since there was no applicable dynamic protection standard for side or rollover impacts, "engineering judgment" determined that padding which could reduce head, neck and upper torso injuries and compensate for the lighter structure in the sides and roof was unnecessary[8]. In other words, not paying attention to protecting people increases casualties.

All cars are only as safe as they are required to be. But due to manufacturers taking advantage of loopholes in regulations, they are nowhere near as safe as consumers believe standards require them to be. For instance, although belts were required in cars since the early 1970's, it wasn't until 1987 that manufacturers were required to certify that they provided protection in an impact. Even today manufacturers are only required to protect tightly belted, average size occupants in frontal accidents to 30 mph.

But with comfort feature (window shade) belts most people are loosely belted, many Americans are somewhat overweight, many accidents are not frontal and not under 30 mph. All these factors lead to occupant movement into contact with interior surfaces, the result of which is that too many people wearing belts (that they think will protect them) receive Severe, Critical and Fatal injuries.

During 1990 and 1991 two significant Regulatory changes have been made which will have a significant impact on future casualties if fully implemented. NHTSA has implemented a dynamic side impact test in FMVSS 214 and announced that Light Trucks and Multi-purpose Vehicles must in the future, meet automotive performance standards from which they were previously exempt. The impact on CAFE of the expected 50 pound weight penalty is negligible.

To realize the full protection of these measures, NHTSA must issue a Final Rule for head injuries as part of FMVSS 214 and must issue Final Rules for Light Trucks and Multi-purpose Vehicles, for dynamic side impact and rollover which have not been done. The history of NHTSA is replete with good proposed rules that never become final.

Of the 47% of the people who wear their belts, how many wear them low and tight across their laps, how many are not overweight, how many impacts are with other cars and at intersections, how many head-on impacts are at 30 mph with the vehicles intentionally lined up centerline to centerline, how many are side or rear impacts and/or rollovers for which no protection is yet required? What is the role of the driver in establishing fatality rates by car make and model? How will airbags change the picture? The answer to these and many other questions will characterize future casualties.

FUEL ECONOMY BACKGROUND

Since the oil crisis of 1974 new car demand has changed the size distribution of the U.S. fleet and new car demand by size is now stabilizing. CAFE has affected the mix of vehicle sizes offered for sale by individual manufacturers. The largest and smallest classes have shrunk while the intervening size classes have grown in sales. The mini-class dropped out of the market going from 11.4% in 1974 to 0.8% in 1990. The large car class went from 21.3% to 12.7% of the market. The overall effect has homogenized the vehicle mix with large cars getting smaller and small cars getting larger[39].

When one analyzes the CAFE improvement from a level of 14.0 MPG in 1974 to 27.8 MPG in 1991, one finds that 86% resulted from technological improvements to passenger cars. In 1974, the average new car fleet inertia weight was 3968 pounds. In 1991, the average was 3178 so the average car dropped 790 pounds or 19.9% in weight. Since every 10% reduction in weights yields a 6.6% increase in CAFE, the increase in CAFE due to weight loss from 1974 was only 13.1% Using Oak Ridge National Lab CAFE data took the 1976 mix and superimposed it on the 1991 fleet. DOE found that the 1991 fleet had only improved its CAFE by 0.2 MPG due to mix shift. Of the total CAFE increase of 13.8 MPG since 1974, 1.8 MPG was due to weight loss, 0.2 MPG due to mix shift and 11.8 MPG or 86% due to technological improvements. If we had traded out engine performance improvements for CAFE gains versus faster acceleration times, we would have had a 1991 CAFE of 30.3 MPG for a gain of 16.3 MPG with 14.3 MPG or 88% coming from technological improvements.

For a given population of cars there is no relationship between CAFE and current levels of Safety. The safety of vehicles has been demonstrated to be easily improved from current levels with significant weight reductions[9]. Safety is related to structural crashworthiness and occupant protection design alternatives, while fuel economy is related to engine and transmission efficiency, power to weight ratio, acceleration performance, drag coefficient and vehicle size (which has weight implications).

A technological improvement in engine performance and efficiency can be used to improve acceleration or fuel economy. But, acceleration is thought to sell cars.

The truth is:

We can address **increased** CAFE Standards and **improved** occupant Safety protection individually, because practical technology is available at reasonable cost to do either or both and both are deserving of our attention.

A reasonable relationship between Safety and CAFE standards can be fabricated but the results will be dependent on the factors considered. History and reality would suggest that a consistent and positive relationship has, can and will continue to exist.

Based on where we are today, only a virtually impossible production mix of vehicles, combined with an irrational disregard for safety considerations which is not in evidence, could reverse and adversely effect the gains in safety of the past twenty years.

CHARACTERIZING CONSUMERS AND MANUFACTURERS

Manufacturer's design and produce cars either to create or satisfy new car market demand, while meeting imposed regulations. Design changes are generally to reduce cost and/or maximize perceived value and profits. Manufacturer's statements about what can be done are based on the perspective that current designs are the result of near perfect satisfaction of customer market surveys.

Cars are reasonably safe when measured by dummy injury measure compliance with Federal Motor Vehicle Safety Standards[10] and are unsafe when measured by their ability to protect real world car occupants from injury and fatality in foreseeable accidents with the technological state of the art of the past twenty years.

More specifically, with regard to CAFE standards, U.S. car models are designed to the industry's perception of the customer's desires in looks, power and performance in each market segment, while production and marketing is geared to sell enough of the "right" cars to meet CAFE requirements. Many Japanese car models are designed with an engine just sufficient to meet adequate but minimum consumer acceleration expectations. U.S. consumers thrive on and buy variations, so the range of alternatives of vehicle size, acceleration performance, handling and accommodations cannot be regulated.

The manufacturer's perception is that, increased fuel economy doesn't sell except in times of high fuel costs. In Europe, more than a dollar a gallon tax on gasoline is an effective consumer incentive for reduced fuel consumption cars. But at current American gasoline prices, high performance even at increased cost and fuel consumption still sells.

Regulators who visualize the national and environmental benefits of improved automotive fuel economy and attempt to use the mechanism of increased CAFE requirements to accomplish it are counteracted by representatives of the U.S. manufacturer's perspective who see it mostly as forcing a change in the sales distribution, favoring cars they don't think the public wants to buy and they have a hard time selling.

It is reasonable to presume that a manufacturer's priority is to design and produce cars that sell - and meet all regulatory requirements. It is therefore understandable that they would resist any public policy (whatever the regulatory change mechanism) which forces them to produce what they perceive as competitively less saleable cars. When the public is thought to value fuel economy as they now (twenty years later) value reduced emissions, air bags and anti-lock brakes, manufacturers will gladly supply it.

Perhaps the role of public policy debate is to gradually adjust public sentiment towards acceptance of socially desirable change even at disproportionate individual cost. But the debate and implementation should be founded in basic engineering principles and technical truths not in rhetoric and perceptions as advanced by opponents of increased CAFE standards.

CHARACTERIZING THE ACCIDENT AND INJURY POPULATION

Accident Statistics - Since the Highway Safety Act of 1966, the fatality rate for all vehicles has declined 50% while fuel economy has doubled. Yet the number and percentage of small cars (with relatively high fatality rates and fuel economy) in the vehicle population has increased dramatically. The more recent reasons for this seeming contradiction are: the greater use of the available restraints, particularly in small cars, the greater number of mid-size cars, the 1977 to 1986 reduction in the number and weight of large cars and the introduction of "passive (padded) interiors."

Table 2, taken from NHTSA evaluations of the effectiveness of Safety Standards, shows reductions in deaths and injuries attributed to regulated safety improvements from the mid-1970's to the mid-1980's.[35]

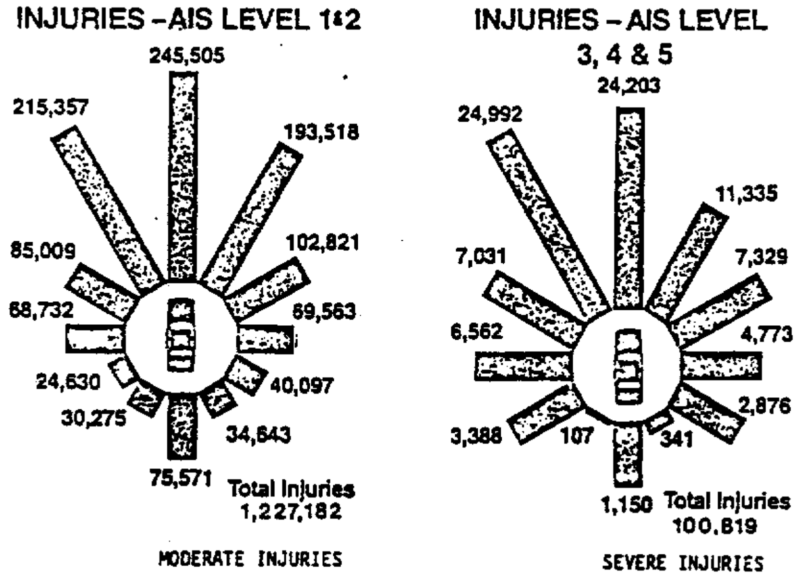
TABLE 2. BENEFITS OF VEHICLE SAFETY IMPROVEMENTS
MID-1970'S V. MID-1980'S

IMPROVEMENT	**LIVES**	**INJURIES**
Front Padding	700	Unknown
Head Restraints	Unknown	64,000
Steering Assemblies	1300	23,000
Windshields	105	47,000
Door Retention	400	Unknown
Roof Strength	110	Unknown
Side Protection	480	9,400
Child Safety	192	Unknown
Fuel Tanks	400	520
Brake Improvement	324	29,700

ANNUAL SAVINGS

1979 Testimony[11] included estimates of the relative number of injuries by severity and accident mode (area of damage) in 1975, reproduced here as Figure 4. The Abbreviated Injury Scale (AIS) is the engineering description of the level of medical injuries. AIS = 1 is minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = fatal. These charts illustrated the 1975 priority need for frontal and frontal angled offset impact protection with 15% restraint usage.

FIGURE 4. 1975 DISTRIBUTION OF INJURIES BY MULTI-DISCIPLINARY ACCIDENT INVESTIGATION (MDAI) DAMAGED AREA AND AIS LEVEL


INJURIES - AIS LEVEL 1&2

INJURIES - AIS LEVEL 3, 4 & 5

INJURIES - AIS LEVEL 6

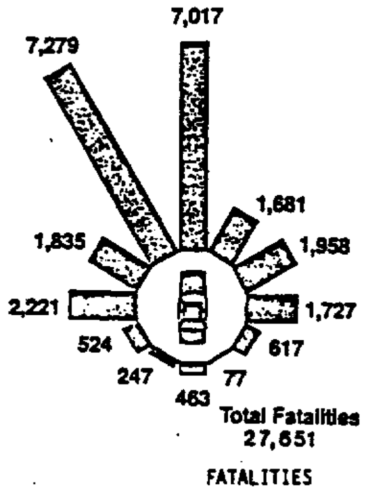


Figure 5, also from that testimony, illustrates that the driver and how he drives effects the fatality rate significantly. Crash Tests of hot cars like Camaro or Nissan Z's, Corvettes and Firebirds, favorites of the younger and more aggressive driving public, indicate that they perform like other cars in the same weight class. Therefore, they must crash at speeds in excess of the protection provided and warrant installation of the most advanced high performance restraints possible.

FIGURE 5. PASSENGER CAR OCCUPANT FATALITIES PER 100 MILLION VEHICLE MILES BY CURB WEIGHT

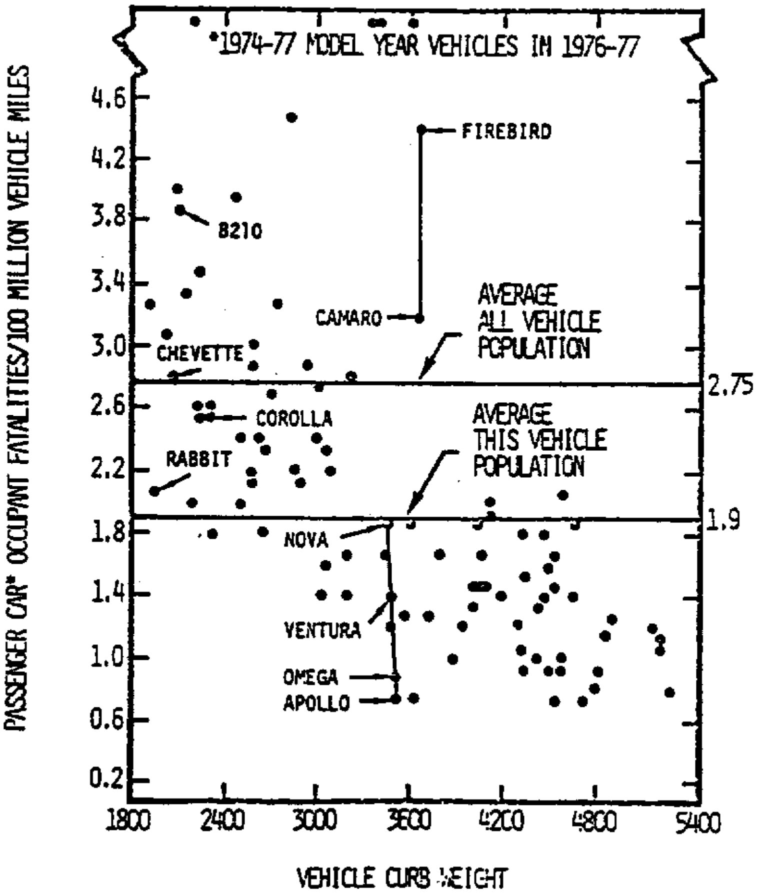


Figure 5 also shows that there were many component features of different versions of the same car (like the Camaro and Firebird, and the GM Nova, Ventura, Omega and Apollo) which effected and determined its fatality rating. That is particularly true of different engine orientation and sizes.

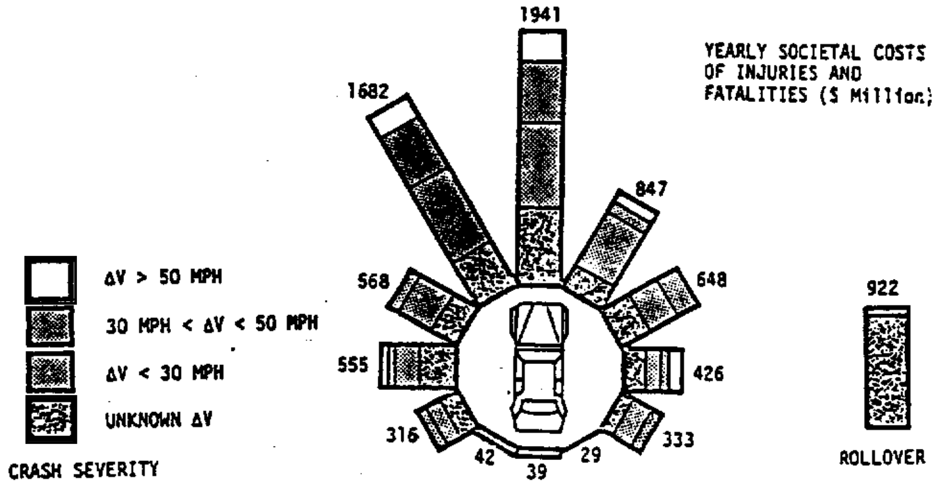
Real world accidents are not reasonably represented by FMVSS 208 dynamic tests. The field distribution of frontal accidents that could be simulated by a dynamic test are shown in Figure 6. Of these FMVSS 208 frontal and 30° angled barrier tests represent about 37% (indicated by *). Real world accident studies indicate that severe injuries occur at the same delta-v particularly as a result of compartment intrusion and represent an additional 43% of the population (indicated by +). While additional tests would be the best assurance of performance in these modes, adjusting the angled barrier test to 45° from 30° is the least change which will add this 43% additional representation to the standard.

Figure 6. ESTIMATED FIELD RELEVANCE FOR VARIOUS TESTS

TEST CONDITION	% Field Accidents	TEST CONDITION	%Field Accidents
Frontal Barrier*	2	Partial Car-to-Car+	14
Partial Barrier+	2	Frontal Car-to-Car*	11
Bumper Underride B	4	Angle Car-to-Car+	13
Partial Underride B	7	Angle Barrier*	24
On-Center Pole	5	Ang Hng Plr Car-to-Car+	5
Off-Center Pole+	9	Undercarriage Hang-up	3
Off-Center Low Pole	1		

Figure 7 is Societal Loss Distribution by damage area mode and delta-v from the Minicars RSV Final Report[5], using the National Crash Severity Study (NCSS)[12].

FIGURE 7. SOCIETAL LOSS DISTRIBUTION



NHTSA in 1982 (based on 1979-1980 National Accident Sampling System [NASS][13]) published a study[14] which illustrates the relationship between various levels of injury and the magnitude of possible error with different statistically manipulated data sources. It also analyzed the National Crash Severity Study (NCSS) file to identify the difference in crash severity between full size and subcompact cars in the 1975 time frame, when most cars were large. It confirmed that with those 1975 cars, the mostly unrestrained occupants of small cars were exposed to a higher distribution of crash severity (about 10 mph higher at 30 mph) as compared to large ones.

The important point here is that with minimum restraint usage, severe injuries and fatalities were not handled as well by small as large cars and light trucks, and therefore represented a large portion of the projected severe casualties. Figure 1 was a projection to 1985 of the societal cost (harm) resulting from small cars at the same level of restraint usage as 1975.

Fortunately, the advent of Mandatory Use Laws and the implementation of FMVSS 208 beginning in 1987 has had and will continue to have an increasingly significant effect in the reduction of all casualties and in small cars. At present even with 47% restraint usage, small cars represent about a third of the total fleet (including light trucks), but more than half of the societal cost (harm) of injuries and fatalities.

The various files roughly summarize the history of casualties to the present as shown in Figure 8.

Figure 8 - HISTORY OF FATALITIES AND ESTIMATED NUMBER OF AIS INJURIES

YEAR	FATALITIES	FAT/100 M VMT	FAT & INJ. in CARS by AIS				
			SER INJ	6	5	4	3
1975	44,525	3.4	206,868*	28k	15k	15k	87k
1980	51,091	3.3	441,674	32	41	42	241
1985	43,825	2.5	378,860	27	35	36	207
1990	44,500	2.1	394,000	28	36	36	210

* MDAI, all other from FARS and NASS

These data confirm that as the percentage of small cars in the population increased to 1980 so also did the serious injuries, particularly in small cars. As the spread in weight decreased, restraint usage climbed and the population stabilized (with small cars around 50%) between 1980 and 1985, serious injuries also declined. The elimination of the mini-subcompact, decreased weight of the large car and moderate improvements in safety of newly redesigned 1980's models contributed to this decline.

By then the distribution of serious injuries was strongly skewed towards small cars. By 1990 growing restraint usage (now at about 50%) is leveling the number of serious injuries as the total mileage increases so the overall fatality rate is decreasing but the disparity in small cars remains because we failed to incorporate advanced safety into them.

In the future, even with over 70% restraint usage there will be a continuing safety disparity, between small and large cars and light trucks, unless the Federal Vehicle Safety Regulations are adjusted to reduce small car casualties while requiring equal barrier performance from all cars and light trucks. One way this could be accomplished by changing the angled barrier test to 45° (from 30°) representing a large percentage of the most frequent and particularly intrusive (in small cars) impact modes.

CHARACTERIZATION OF COLLISION AVOIDANCE TECHNIQUES

The most prominent and popular devices in this category are and will be Electronic enhanced controls, the currently most popular of which is the Antilock Braking System (ABS). Several of these systems were incorporated into the Minicars Advanced Research Safety Vehicle[15] including ABS, a radar activated Cruise Control Following system, an Emergency Braking System and an Electronically Shifted Transmission. Earlier studies at General Motors Research Laboratories, had demonstrated the feasibility of such Driver Aids including passive optical lane guidance and alcohol interlocks to prevent drunks from driving.

These techniques have perceived value to the consumer and need not be incorporated by regulations because they are active all the time and impact driver performance. Their sales will enhance safety and will not unduly encourage more aggressive driving as is sometimes feared.

CHARACTERIZATION OF THE STRUCTURAL DESIGN ALTERNATIVES

Structural design considerations - To characterize the difference in fatality rate between small (2200 lbs.) and large (3300 lbs.) current cars, consider that regulations require equal non-life threatening restrained occupant protection at 30 mph.

But when with unrestrained occupants these cars run into each other, each going 25 mph for example, the large car occupants experience a mass determined 20 mph non-life threatening collision, while the small car occupants are in a 30 mph life threatening collision. When these same cars with restrained occupants run into each other each going 35 mph (the NCAP test speed), the large car occupants are in a mass determined 28 mph near-life threatening collision, while the small car occupants are in a 42 mph fatal collision.

There are then two problems with frontal Crashworthiness performance and Standards: To provide equal protection at the accident severity level of current large cars, Small cars must meet the FMVSS 208 injury criteria at higher speeds. And second, the capability of all cars to protect in the frequently occurring, strongly angled or offset impact mode must be enhanced. These were part of the NHTSA Advance Notice of Proposed Rule Making (ANPRM) on FMVSS 208 in 1977 but it was never implemented.

It is important to point out here, the significance of implementing the dynamic test requirements of FMVSS 208 in 1987. Advocates and the public understood the auto companies to be resisting the installation of airbag restraints (which was certainly true). But more than that, they were resisting a shift from hardware engineering tests to biodynamic (human movement) tests with Biomechanical Injury Criteria results. For the first time in 1987, it didn't matter how the structure performed in an accident, it only mattered how the occupants came out of it.

That was the foundation of the 1974 Minicars RSV program and the engineering consequences still have not been embraced by Industry's management. Whereas in the past automobiles were designed principally by mechanical and structural engineers who made the parts fit together and last and deform within specifications, from 1987 on (with FMVSS 208 implementation) the structure is primarily the transportation element and secondarily the human accommodation.

The key to future reductions in injuries and fatalities lies in occupant protection thru decisions of the Systems Design Engineer, the Biomedical Engineer, the Biodynamicist, the Restraint Engineer, and the Computer Simulation Scientist. Indirectly, these same people are the key to increased fuel economy.

The reason is that adjusting the accommodation structure to improve the crashworthiness (the deceleration and resistance to intrusion) of a two to four thousand pound car adds much more weight than an advanced restraint system (the surfaces which contact the occupant) which only needs to bring a one to two hundred pound occupant to rest without a second collision which is too hard or too fast.

This fundamental consideration means that once you commit to an airbag restraint system (with a passive interior), its performance can be adjusted without weight penalty to protect to the limit of excessive structural intrusion which even in many current small vehicles is 40 mph (1.75 times as much energy as 30 mph) in frontal barrier and 30 mph in strongly angled or offset impacts.

Having finally penetrated this resistance to designing vehicles for people, the Regulatory efforts to improve protection in all cars in side, rollover and rear impact modes must continue and be finally implemented.

There are many structural alternatives to increase safety performance but in view of the ease (low weight and cost) with which it can be done thru restraints and passive interiors it seems likely that structures will be optimized, that is, weakened and lightened to just meet safety standards and provide more exhilarating acceleration, unless safety and CAFE standards are increased.

Only two significant structural modifications are likely to gain favor: (a) transfer and distribute offset loads across the whole structure and (b) strengthen the passenger compartment just enough to limit excessive interior intrusion to meet FMVSS test requirements with restraints and passive interiors.

If test standards are increased:

Since an air cushion restraint system can accommodate higher amplitude deceleration, increased front end stiffness will be accomplished by substituting higher strength steel and/or more energy absorbing, omnidirectional sheet metal crushable elements instead of buckling beams so as to minimize any weight increase.

Increased distance between the steering wheel or dash and the front seat occupants chest and head will provide for more occupant stroking (at lower acceleration levels) before contacting an interior surface. Longer seat tracks for more nominal front seat room in conjunction with air bags wouldn't add weight.

Rotating or altering the location of the engine is practical with no weight penalty. Front wheel drive allows for longitudinal or transverse engines and a transverse engine allows for the block to be located in front of the driver or passenger. Since left frontal offset and angled impacts are more frequent and severe, the engine orientation which minimizes intrusion of the steering wheel and "A post" into the driver would be most protective.

Transferring and distributing offset loads across the whole structure is being facilitated by finite element computer programs. Modified designs with minimum weight increase can greatly enhance offset and strongly angled impact performance, or the same programs can be used to decrease weight in the currently regulated frontal impact mode[34].

Strengthening the passenger compartment to reduce interior intrusion can often be accomplished by better attachment and welding techniques of the existing structural elements. If there were a regulatory requirement to test in the offset and strongly angled impact mode or the 45° angled barrier rough equivalent, transfer of front end structural loads for absorption through the door, its structural surround and the rear of the compartment would be considered.

CHARACTERIZING RESTRAINT ALTERNATIVES

During the interval from 1970 to 1987 the requirements of FMVSS 208 regarding front seat restraint installation was met by three point harnesses. Less than 15% of the occupants used them until passage of mandatory seat belt usage laws in 1985-87. There was no regulated dynamic test performance criteria, so that while some manufacturers adjusted anchor points for good performance over a range of occupant sizes and others improved the design and performance of the emergency locking retractors, there was little accident data collected on the effectiveness of restraints and less on the effectiveness of restraints in accidents of high severity (greater than 30 mph change in velocity).

Most of the regulatory effort was to affect the implementation of automatic restraints (automatic belts and air bags), to encourage public "Buckling-up" and the States to enact "Mandatory Usage Laws" and to make it less awkward to wear belts by the incorporation of so called "comfort features" which allowed the torso belt to accumulate slack for freedom of movement at the cost of extended occupant forward motion.

During that same interval much dummy and restraint research was accomplished and many high performance concepts were developed and demonstrated in all seating positions and all size cars and trucks. These are detailed in NHTSA Minicars Contract Reports[16-25]. There were many additional efforts, by other contractors namely Calspan, by GM with their 30 mph GM ACRS system (produced during 1974 to 1976), as well as several 30 mph fleet installations by Ford and Volvo, and a variety of 30 mph two (VW) and three point (GM) automatic belt systems.

Minicars, beginning in 1972, developed for NHTSA and any manufacturer who wanted to use it, advanced airbag and belt harness systems to protect driver and passengers in impacts of up to fifty miles per hour in small and large cars[26-29]. Of course there were structural modifications required of then current vehicles to protect at above 40 mph in most cars, since intrusion became excessive due to poor design tecniques.

The key to the high performance was associated with: rapid rise times of multiple limited-volume airbags, deep force limiting knee bolsters, pretensioning thru two point airbelts, the orientation and energy absorption stroking of the steering column, force limited anchor points, laminated and partially fixed side glazing and padding at potential interior contact points. These advanced systems did not require the combination of three point harness and airbag (the now popular Supplemental Restraint System).

Although FMVSS 208 airbags and automatic belts were finally implemented in 1987 after 17 years of delay, there is little hope that even by 1994, we will realize the dream of gross small car casualty reduction. This is because as mentioned earlier, the standard does not recognize the inherent deficiency of a barrier test replicating a real world car to car accident in an offset and/or strongly angled impact mode and because the auto companies will do little more than the standard requires.

As early as 1977 Minicars at NHTSA's request, polled the industry[30] as to which of a variety of alternative current restraints of differing performance levels they would implement in which cars. The auto industry candidly stated that if required by FMVSS 208, it would implement a minimal safety compliance by primarily installing automatic belts, and could not even foresee implementing airbags in small cars.

The alternative systems included modifications to the 1974-1976 GM ACRS, with techniques developed for Subcompact Cars and with potential for increased protection at higher velocities. The GM ACRS had been developed and was updated for large cars, a productionized steering column modification and knee restraint was suggested for smaller car installation and a new shallow angle stroking column modification[29] was suggested for installation in the smallest cars. Harnesses included torso belts attached to the door with knee bars below the instrument panel, webbing-lock retractors, force limiters, belt pretensioners and column retractors.

The technological capability to increase the protection of occupants in conventional small cars in 40-plus mph barrier equivalent impacts was demonstrated in 1979[24], by a Minicars driver airbag upgrade of an early model Volvo production car with a Minicars passenger Air belt and independent crash testing at Dynamic Science in a variety of accident modes including offsets. The modifications demonstrated involved no significant increase in small car cost or weight.

Maintaining the current inequity in safety performance protection of small cars is unconscionable yet is the result of regulatory compromise and inaction as well as manufacturers interpretation of minimum performance. Those interpretations are limiting the implementation of air bag restraints in small cars where they are most needed, and favoring automatic belts which are cheaper.

CHARACTERIZING PASSIVE INTERIORS

In conjunction with its development of high performance air bags for small cars in the early 1970's, Minicars, Inc. attempted to provide truly passive protection in all accident modes. The passive interior concept was epitomized in the Minicars Research Safety Vehicle (RSV), applied to the Chevrolet Citation in the Modified Production Vehicle program (MIV) and incorporated and publicized to some extent in General Motors X and J cars in the late 1970's and early 1980's.

The extent to which the initial implementation could be expanded and its effectiveness in reducing AIS 4 to 6 injuries increased, has been the subject of a six year research effort using real world injury accident case data, NHTSA and other published research results, manufacturer's crash test data and computer simulations and analysis.

The analytical protocol used was previously described and included case work examples[31]. A paper to be given at the 13th International ESV Conference in November[32] describes the effectiveness of passive interior modifications in mitigating head and neck injuries in frontal, side and rollover accidents. The performance in each accident mode with and without alternative restraints, are compared to the injuries in the manufacturer's as-built test results. Consideration is also given to the injuries which would have resulted if improved passive interior components had been installed[33] Recently available manufacturer's research information on offset frontal and rollover impacts has provided the data to complete the computer analysis.

In summary, the results indicate that a force limited plastic covered metal contact surface, separated from the main structure above the belt line by an inch or two, would have a dramatic effect on head and neck injuries regardless of restraint usage and performance. General Motors, which recognized this effect in 1980 and committed to it in 1984 has in 1991 expanded the depth of molding in some models at the roof rail and A-post to begin this process. While a passive interior, like a helmet, protects in many frequently occurring circumstances, in high speed frontal accident modes, it is a supplement to, but no substitute for, effective restraints.

In offset frontal impacts, the structural intrusion of the A post, instrument panel and the steering wheel hub have combined with restraint ineffectiveness and high angular principal directions of impact force (PDIF) to result in brain damaging head contacts. They are entirely foreseeable, confirmed by manufacturer's tests and mitigatable by increasing the depth of force limited, high efficiency padding on the A post, windshield header and roof rail.

While not a substitute for structural load transference and alternate steering column coupling to the front end to limit the intrusion, it would at least deal with the restrained occupants severe injury contacts to the column and A post in 30 and 35 mph vehicle delta V impacts.

In side impacts, it appears that these techniques will be implemented more extensively and extended to meet the requirements of the revised FMVSS 214 dynamic tests. However, particular attention should be paid to head contacts on the roof, roof rails and on the far side as a result of unrestrained occupant motion towards the intruding door/side structure.

In rollover impacts a number of injury mechanisms have been identified and categorized. Head and neck axial compression alone and in combination with sheer and flexion forces, lead to cervical fractures and spinal cord injury at relatively low force levels compared to that resulting in brain damage. Furthermore these force levels result from head to roof contact velocities with a seated body orientation in the range of 2 to 3 meters/sec. which are typical during roll initiation with torso augmentation, or during roof and roof rail contact through a combination of vertical and centrifugal torso and roof intrusion velocity.

In summary the countermeasures for rollover protection include:

1) moderately increasing roof support strength to eliminate roof collapse and reduce intrusion velocity, by increased post sections and gauge, fixed side glazing and reduced side glazing area;

2) facilitate the natural protection of the neck musculature by inclining and reducing the pocketing effect of the roof surface;

3) increasing head room and restraint effectiveness against vertical occupant motion;

4) incorporating a force limiting, non-pocketing head liner separated from the roof by an inch or two and finally

5) laminated side glazing to reduce the possibility of partial ejection and head to ground contact.

CHARACTERIZING VEHICLE DESIGN TO ACHIEVE FLEET PERFORMANCE

Based on the characterizations (from twenty years of observed behavior) of the consumer and manufacturer in a regulatory environment, injury accident data bases, industry and Government research and development test data and available design alternatives, we can apply the Minicars RSV design/performance methodology to understand the consequences of Regulatory options.

For this study and based on regulatory implementation history, we chose modest and reasonably achievable goals for phased implementation in 1996 and for 2001.

Safety for 1996: Modify FMVSS 208 to substitute a 35 mph frontal and 45° angled barrier test for small cars, retain the 30 mph frontal and 45° angled barrier test for large cars and implement the Paragraph S8.3 rollover test with an added (4000 newton) neck compression injury criteria for all cars.

Fuel Economy for 1996: Achieve a 34 mpg CAFE simultaneous with Safety improvements.

Safety for 2001: Raise the above FMVSS 208 frontal and angled safety protection performance to 40 mph and conduct all FMVSS 214 Side Impact tests at the same speed.

Fuel Economy for 2001: Achieve a 40 mpg CAFE with known technology and simultaneous with Safety improvements.

Since manufacturers have chosen to embrace Regulation as the performance target rather than as a performance minimum, the study purpose is best served by predicting what design alternatives manufacturers would implement and how difficult it would be for them to achieve this performance. Alternate options can also be analyzed.

STRUCTURAL DESIGN CHOICES for 1996

The analysis is based on selecting a typical car in each size category and estimating the effect on weight of modest design and engine changes which could be accomplished in the near term. Unspecified Safety modifications weighing one hundred pounds were also included in the estimate. The estimates are backed up by at least one current production car in the category. In other words, the effect on the average of cars in a class is considered by improving all cars performance to that represented by a "near-best-in-class" since consumers require variations. The weight reductions and basis for changes are shown below in Table 3.

TABLE 3. STRUCTURAL DESIGN CHOICES FOR 1996

Typical Size	MFG Model	EPA/ORIG. Weight	Redesign Weight	Design Change	Change Basis
Large	GM Caprice	4000	3500	TRNSV FWD	LRSV
Midsize	GM Cutlass	3500	3000	TRNSV FWD	LRSV
Compact	Ford Escort	2500	2500	HSLA STL	C/C RSV
Subcmpct	Honda Civic	2500	2500	HSLA STL	CRX

SAFETY IMPROVEMENT DESIGN CHOICES BY CLASS for 1996

The choices were made to achieve the required performance with the least leadtime, structural modifications, weight penalty and change in current or planned product technology. The choices and performance are shown below.

Size	Restraints		Accident Mode Performance (MPH)			
	Driver	Pass.	Frontal	45°	Side	Roll
Large	Airbag	Airbag	30	30	33	30
Midsize	Airbag	Airbag	30	30	33	30
Compact	Adv. AB	Adv. AB	35	35	33	30
Subcmpt	Adv. AB	Adv. AB	35	35	28	30

For the large car, this means slightly improved roof strength, upper structure passive interior, laminated side glazing, the already included SRS airbags, ABS and Contoured side impact padding.

For the midsize car, this means slightly improved roof strength, upper structure passive interior, laminated side glazing, the already included SRS airbags, ABS and Contoured side impact padding.

For the compact car, this means improved roof strength, HSLA fender wells and catwalks, upper structure passive interior, laminated side glazing, uploading and compartmenting the driver side SRS airbags[26] on a stroking RSV steering column[29], installing an advanced airbag on the passenger side, ABS and contoured side impact padding.

For the subcompact car, this means improved roof and A pillar strength, HSLA fender wells and catwalks, improved door beam hinge and latch attachs, upper structure passive interior, laminated side glazing, uploading and compartmenting the driver side SRS airbags on a stroking RSV steering column, installing an advanced airbag system on the passenger side, ABS and contoured side impact padding.

ENGINE / TRANSMISSION / DRIVE TRAIN DESIGN CHOICES for 1996

For each size car, the choice is for Four cylinder, sequential fuel injected, multi-ported, transverse, front wheel drive with electronically shifted five speed transmission. Application of a near-best-in-class choice results in the following CAFE.

Typical Size Compartment	EPA/ORIG. avg. mpg	Redesign mpg	%Share	ENG/TRNS Basis
Large	23.8	28.0	13.3%	SAAB 9000S
Midsize	26.2	32.2	27.6%	Chev. Corsica
Compact	28.9	40.7	31.3%	Pontiac LeMans
Subcompact	31.6	40.9	27.8%	Honda Civic
Average all cars	27.8	36.0	100%	36.0/27.8 = 129%

The tables above show that it is within current technology to achieve the desired safety and fuel economy performance goals. Since in every case a tested design or production example is available from which to initiate component redesign, the 1996 target is possible.

The Safety situation is much the same for 2001. Most of the higher performance protection will be achieved with upgraded restraint and passive interior components rather than thru a change in technology. Weight reductions will be possible through material substitutions and lighter engine/transmissions.

Size Compart	Volume	EPA/1996 Weight	Redesign Weight	Design Changes	Basis
Large	125 cu. ft.	3500#	3250#	MAT'L SUBST.	LRSV
Midsize	115 cu. ft.	3000#	2875#	MAT'L SUBST.	LRSV
Compact	105 cu. ft.	2500#	2500#	HSLA STL	C/C RSV
Subcmpct	90 cu. ft.	2500#	2375#	HSLA STL	CRX

In addition to the improvements due to weight reduction shown above, the CAFE improvements will come from engine efficiency efforts, and a kind of standardization between car models in the same class on engine/transmission designs, controls and performance exhibited by the best-in-weight-class plus a modest adoption of new technologies as dicussed below. Consumers of the Compact and Subcompact vehicles will give up top-end performance as they will with alternate fuel, electric and hybrid-electric power plants. The results show a 40 mpg CAFE is possible.

Typical Size Compartment	EPA/ORIG. avg. mpg	Redesign mpg	% Share	ENG/TRNS Basis
Large	23.8	31.3	13.3%	CmryW/Saab9000
Midsize	26.2	35.3	27.6%	EscW /Corsica
Compact	28.9	43.7	31.3%	Ford Escort M4
Subcmpct	31.6	48.8	27.8%	Civic M5/HF
Average all Cars	27.8	40.1	100%	40.1/27.8=144%

FEASIBILITY OF 34 MPG BY 1996 AS DEMONSTRATED BY PRESENT VEHICLES

Analysis of 1990 CAFE data confirms that obtaining a 34 MPH CAFE for 1996 is feasible with present technology and vehicles. The 1990 fleet mix by weight is shown in the table below. Each weight class has a technology leader which is the best in the class as shown. If every vehicle in the class was as fuel efficient as the best vehicle in the class, the 1990 CAFE would have been 34.4 MPG versus the 27.8 MPG actually obtained. Since this is a fixed mix and weight scenario by definition, no downsizing or weight reduction has to be done to obtain this CAFE. Present vehicles in every size and weight class already exist to demonstrate the feasibility of meeting 34 MPG by 1996. Even if the next four lower vehicles in each class were used instead of just the top vehicle, the 1990 CAFE would still be 32.5 or 4.7 MPG better than actual 1990 CAFE[40,41].

1990 Best In Weight Class 34.4 MPG Analysis

Class	1750	2000	2250	2500	2750	3000	3500	4000	4500	5500
Share	0.01	1.3	1.4	12.6	10.4	31.0	31.3	11.0	1.07	0.01
MPG	65.4	56.0	59.2	42.2	46.9	33.2	33.7	25.6	22.9	13.2

FEASIBILITY OF 40 MPG BY 2001

Analysis of 1990 CAFE data also confirms that obtaining a 40 MPG by 2001 is feasible without a mix shift or downsizing by materials substitution to reduce weight and modest introduction of new technology. With a reduction of only 200 pounds from the present 3,171 average weight to 2,974 pounds and no shift to a smaller car mix, the 1990 best in class fleet would attain 37.5 CAFE as shown in the following table. Retention of the present size mix is possible since there are multiple weight classes for each size class.

1990 Best In Class 37.5 MPG Analysis

Class	1750	2000	2250	2500	2750	3000	3500	4000	4500	5500
Share	0.7	1.3	7.5	11.4	21.7	31.2	20.2	5.6	0.49	0.01
MPG	65.4	56.0	59.2	42.2	46.9	33.2	33.7	25.6	22.9	13.2

Any number of new technological options can be used in conjunction with materials substitution or alone to accomplish the modest CAFE improvements necessary to bring the 1990 best in class levels to 40 MPG in the ten years until 2001. The following is a list of such technologies and their potential. Only a few need to utilized in part to go over 40 MPG.

The present analysis conservatively assumes auto companies will realize only 3.5% in improvements in CAFE from new technologies out of a potential CAFE improvement of 15-20% within the next ten years. New technological improvements such as further reductions in aerodynamic drag, intake valve control and improved transmissions will occur, the only issue being the extent of their market penetration. Beyond these realized new technologies, the auto companies will realize fuel economy credits from the production of alternative fuel vehicles which lower any CAFE standard they have to achieve. General Motors has already certified a Flexible Fuel 3.1 liter V-6, 3750 lbs. Lumina for 1991 at a CAFE adjusted gas mileage of 35.7 mpg versus 23.6 mpg for the gasoline LUmina. With maximum utilization of new technologies, including phase-in of direct injection stratified 2-stroke engines in compact cars, the auto companies could attain CAFE levels of 45.8 mpg by 2001.

2001 Technologies	Vehicle MPG Improvement	Fleet CAFE Improvement
Advanced Aerodynamics C_D=0.2-.30	5%	3%
Intake Valve Control	6%	2%
5-spd Auto. Transmission	2.5%	2%
Engine Improvements	5%	2%
Low Mass Advanced Piston		
Ceramic Valves		
5-valve Engine		
Modulated Displacement		
Increased/Variable Compression		
Alternative Engines	20%	5%
Direct Injection Stratified 2-Stroke		
Direct Injection Diesel		
Hybrid Stored Energy		
Advanced Materials	6%	3%
Graphite reinforced plastics		
Improved Tires C_R=0.0075	.5%	.5%
Alternative Fuels	3%	3%

Vehicles today which already utilize technologies such as multi-valve engines and efficient packaging can easily be improved with existing technology such as 5-speed automatic transmissions and intake valve control. The following example shows how application of proven technology will enable a Toyota Camry to go from 32.8 to 41.3 mpg.

TOYOTA CAMRY	Actual 1988 Specification	Potential 2001 Specification
Curb Weight	2811	2575
Drag Co-efficient	0.36	0.30
Interior Volume (cu. ft.)	89/12	89/12
Frontal Area (sq. ft.)	20.45	20.45
Engine Type	4-cyl/4 valve DOHC	Same w/ intake valve control
Displacement (CID)	122	110
Transmission	L-4/(M-5)	L-5/(M-6)
0-60 mph time (sec)	9.2	11.5
Fuel Economy (mpg)	32.8	41.3

The additional technologies used by 2001 which are not presently in the Camry and their fuel economy benefit are as follows:

Technology	Fuel Economy Benefit
10% Weight Reduction	6.6%
Drag Reduction II	2.3%
Intake Valve Control w/ 5-spd Auto Transmission	6.5%
AdvancedFriction Reduction	2.0%
Advanced Tires	0.5%
Improved Accesories	0.2%
Engine/Ave Acceleration	7.5%
2001 Totals	25.9%

POTENTIAL SAVINGS IN FATALITIES AND INJURIES.

When DOT published its final report in 1980 determining that mass-production of the Research Safety Vehicle was feasible, DOT concluded: "If all cars on the highways contained the safety of the RSV, annual deaths would be reduced by more than 12,000."[43] Based on the analysis in this study, our best estimates are that with current regulations and their scheduled implementations, in spite of increased population and vehicle miles travelled, by 2001 auto occupant fatalities and injuries will have been stabilized at ten percent lower than current levels, but with continuing safety disparities between small and large cars and light trucks because NHTSA failed to require the advanced safety counter-measures proposed in the 1970's. The FMVSS 208 modifications proposed in this study would correct the disparities adding an additional ten percent benefit, while achieving 40 mpg CAFE levels by 2001.

<table>
<tr><th colspan="8">PROJECTED ANNUAL FATALITIES AND INJURIES FROM FMVSS 208 and ADDING FMVSS 214</th></tr>
<tr><th rowspan="2">YEAR</th><th rowspan="2">FATALITIES</th><th rowspan="2">FAT/100 M VMT</th><th colspan="5">FAT & INJ. in CARS by AIS</th></tr>
<tr><th>SER INJ</th><th>6</th><th>5</th><th>4</th><th>3</th></tr>
<tr><td>1990</td><td>44,500</td><td>2.1</td><td>394,000</td><td>28</td><td>36</td><td>36</td><td>294</td></tr>
<tr><td>1995</td><td>42,500</td><td>2.0</td><td>360,000</td><td>26</td><td>30</td><td>30</td><td>274</td></tr>
<tr><td>2000</td><td>40,000</td><td>1.8</td><td>340,000</td><td>24</td><td>27</td><td>28</td><td>261</td></tr>
<tr><th colspan="8">ESTIMATED ANNUAL FATALITIES AND INJURIES FROM PROPOSED CHANGES IN FMVSS 208</th></tr>
<tr><td>2000</td><td>36,000</td><td>1.6</td><td>300,000</td><td>22</td><td>20</td><td>26</td><td>232</td></tr>
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