NHTSA SIDE IMPACT RESEARCH: MOTIVATION FOR UPGRADED TEST PROCEDURES

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ABSTRACT

This paper presents the results of a study on crash conditions and occupant characteristics in side impacts to support the development of advanced side impact test procedures. The US vehicle fleet has been changing in recent years with a growing population of light trucks and vans, and the rapid introduction of side impact inflatable restraints for both thoracic and head protection. The study utilizes the US NASS/CDS, and FARS and GES (1990-2001) to characterize the current and projected US side crash environment in order to identify opportunities to improve side impact protection for the modern US fleet.

INTRODUCTION

Federal Motor Vehicle Safety Standard (FMVSS) 214, the United States (US) side impact regulation for passenger cars establishes minimum requirements for thoracic and pelvic protection in intersection type vehicle-to-vehicle side crashes [1]. Full compliance by all passenger cars was required by the 1997 vehicle model year. Full compliance by trucks, buses and multiple purpose vehicles with a GVWR of 6,000 pounds or less, was required by the 1998 model year. While not addressed in FMVSS 214, head trauma is partly addressed by the upper interior requirements of FMVSS 201 for which full compliance is required by the 2003 model year [2]. The optional FMVSS 201 side pole impact test adds requirements permitting, but not requiring, the installation of dynamically deploying head protection systems.

The FMVSS 214 dynamic test simulates a 90º impact of a vehicle traveling 30 mph (48.3 km/h) into a target vehicle traveling 15 mph (24.2 km/h). The current striking barrier in dynamic FMVSS 214 is generally representative of a passenger car in terms of weight, front geometry profile, and linear stiffness of the front structure [3,4]. The FMVSS 214 dummy represents a 50th percentile male. The optional FMVSS 201 side pole test simulates a 90º impact of a vehicle traveling 18 mph (29 km/h) laterally into a rigid pole and also incorporates a 50th percentile male dummy.

Even after full implementation of FMVSS 214, the remaining side impact safety problem is considerable. Side impact accidents of light vehicles, i.e. passenger cars, and light trucks and vans (LTVs), result in over 9,700 fatalities each year (2001 FARS [5]).

This paper focuses on a study of crash conditions and occupant characteristics in side crashes on US roads. The study objective was to identify opportunities to improve side impact protection for the modern US fleet and to support the development of advanced side impact test procedures. The study is part of the National Highway Traffic Safety Administration (NHTSA) research to improve occupant protection in side impact crashes for the light vehicle US fleet.

First, a brief overview of the modern US fleet is presented. Next, the crash data study methods and results are presented. Finally, in the discussion section, the ensuing advanced side impact test procedures that are under research and development by NHTSA are presented.

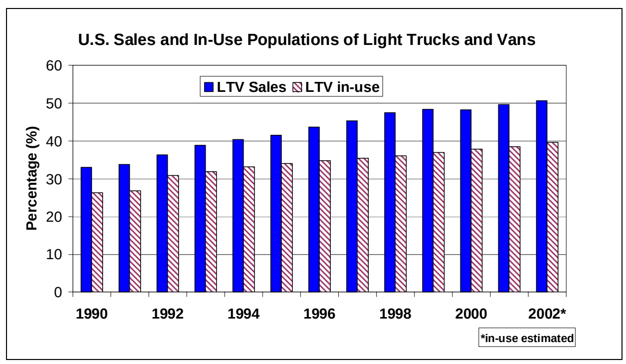

Figure 1. Data Source: Automotive news Market Data Books.

OVERVIEW OF THE MODERN US FLEET

LTV sales have grown from 33% of the new US vehicle sales in 1990 to over 50% in 2002 (Figure 1). The LTV population has grown from 26% of light vehicles on US roads in 1990 to around 40% in 2002 and, based on current sales data, is projected to continue growth.

There has also been a rapid introduction of side impact inflatable restraints for both thoracic and head protection in the US fleet (Figures 2 and 3). As an example, 21% of passenger cars sold in 2002 had head air bag systems installed as compared to 0.04% in 1998. Curtain bags are becoming the most popular amongst head air bags systems, in particular for sports utility vehicles (SUVs) (Table 1).

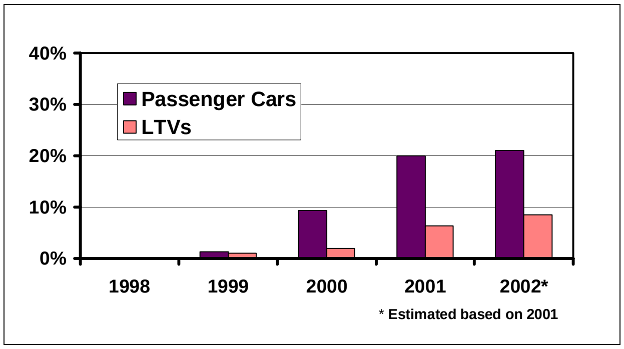

Figure 2. Driver head air bag installations in new vehicles (combo and curtain systems).[1]

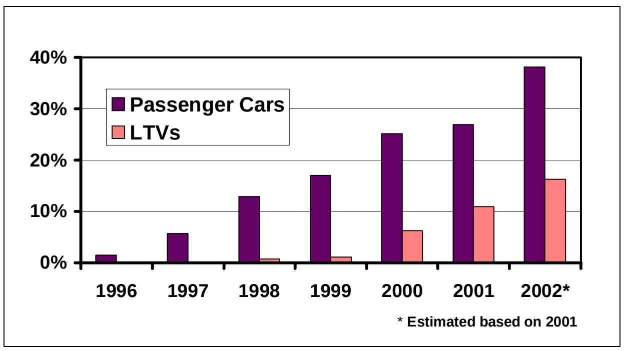

Figure 3. Driver thorax air bag installations in new vehicles (includes combo air bags).

Table 1. 2001 Head Air Bag Systems Availablity

Head Airbags		Combo	Curtain	ITS
2001 PCs	*Std*	17%	16%	2%
	Opt	13%	2%	0%
2001 SUVs	*Std*	3%	13%	None
	Opt	9%	32%	

According to the Automotive Occupant Restraints Council, 70% of all new 2004 North American vehicle make/models will offer head curtains and/or tubes and 45% of new 2003 vehicles will offer thorax bags [6]. The installation rate may be as low as 2% on some model lines and is affected by factors such as cost and consumer awareness.

Despite rapid introduction in recent years, the population of vehicles with side air bags on US roads is still small. Based on recent sales data, it is estimated that, by the end of 2001, only 1.4% (1.8 million) passenger cars and 0.6% (0.5 million) LTVs on the US roads had head air bags installed, and 5.2% (6.57 million) passenger cars and 1.35% (1.15 million) LTVs on US roads had thorax air bags.

Improved Side Crash Protection of Side Impact Inflatable Restraints

Vehicles with modern countermeasures, specifically side air bags systems appear to have improved side impact protection. Using a simple comparison of star ratings in the US side New Car Assessment Program (NCAP), recent model year passenger cars and LTVs equipped with thorax air bags provided better overall thoracic and pelvic protection than vehicles not equipped as such (Figures 4 and 5). On a scale of 1 to 5, a 5-star rating indicates the least injury risk or highest level of safety [7]. The vehicles equipped with thorax air bags may have other structural enhancements that contributed to their improved safety performance.

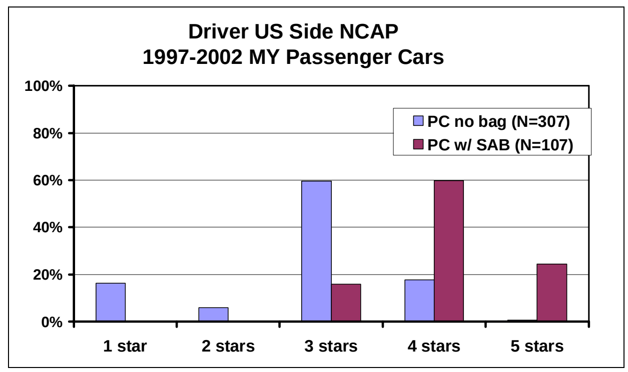

Figure 4. US side NCAP passenger car rating with/without thorax side air bags.

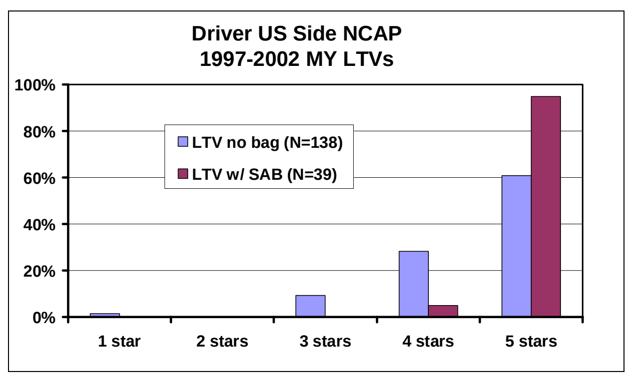

Figure 5. US side NCAP LTV rating with/without thorax side air bags.

The US side NCAP testing follows the FMVSS 214 configuration with a 5 mph increase in impact speed. The program also uses 50th percentile male dummies as surrogates for driver and rear passenger occupants.

Using the head protection measure in FMVSS 201 side pole tests, vehicles equipped with head curtain and combination side air bag systems provided considerable head protection with the Head Injury Criterion (HIC) well below the required limit (Figure

[1] Data source: Ward's Automotive Yearbook. In Figures 2 and 3, the assumption is that 15% of vehicle models with optional side air bags actually had air bags installed. Combination air bag systems are the seat mounted head/thorax combination air bags

6). Seven of the ten vehicles tested had head curtains and three had combination head/thorax air bags. As an example of the potential to improve head protection, two matched vehicles with and without head protection air bags were crash tested in the 201 pole test configuration. HIC decreased more than ten fold in the vehicles with head protection (Figure 7). Special crash investigations by NHTSA of cases involving head side air bags systems, although limited in numbers, also indicate that head air bags systems are successful in reducing head injuries [8].

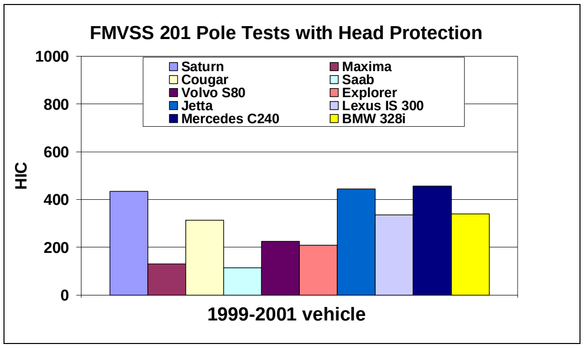

Figure 6. FMVSS 201 pole test HIC limit is 1000.

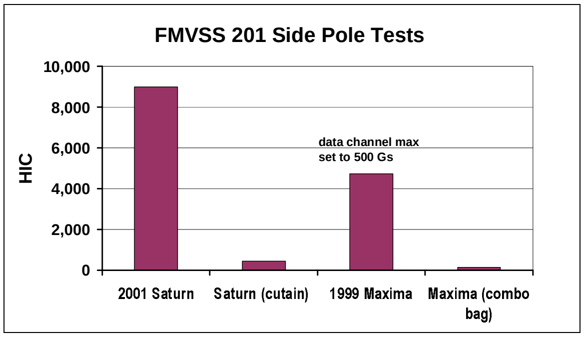

Figure 7. FMVSS 201 pole tests with and without head side air bags.

US SIDE CRASH ENVIRONMENT

Methods

A study of side crashes utilizing the US National Automotive Sampling System/Crashworthiness Data System (NASS/CDS), the US Fatality Analysis Reporting System (FARS), and the US General Estimates System (GES) (1990-2001) was performed. To have a better indication of the future US side crash safety problem, the emphasis was on crashes with belted occupants in side struck vehicles of model years 1995 and later. Vehicle age affects or sampling variability across calendar years are not addressed in this study. No model year restrictions were made on the striking vehicle in both NASS/CDS, and FARS and GES populations.

While FARS is a census of all fatal traffic crashes on US roads, NASS/CDS is a data system based on a nationally representative sample of crashes. Since the collected data are based on a sample, the NASS/CDS national estimates are statistically weighted. In this analysis, the NASS/CDS results are considered useful point estimates for sample sizes $\geq$ 20. The model year and restraint filters were relaxed for certain aspects of the analysis to allow for larger sample sizes. The overall NASS/CDS study population was defined as follows:

- **People:** near/far side occupants, seated in first two rows, not completely ejected
- **Vehicles:** light passenger vehicle (under 10,000 lbs GVWR, towed from the scene, inspected by NASS)
- **Damage**: primary damage to the side, no rollover, no top damage, minor secondary front, rear, or undercarriage damage

In the NASS/CDS population, a nearside occupant is seated on the side of the vehicle with the primary damage. A farside occupant is seated on the side pf the vehicle opposite to the side with the primary damage. In the FARS and GES populations a nearside occupant is seated on the same side as the initial point of impact. Belted occupants are those restrained by 3-point belts.

Side crashes involving three classes of crash partners (passenger cars, light trucks and vans, and narrow objects) were studied. Occupant exposure was addressed relative to seating position, restraint use, age, gender, height, and occupant proximity. Occupant injuries were addressed in terms of severity, equivalent fatality units (EFUs), injured body region, and injuring contacts. EFUs are cost-weighted combinations of injuries and fatalities including both economic and quality of life costs [9]. Crash conditions including collision partner and delta-v were examined. The absolute size of the principle direction of force (PDOF) relative to 12 o'clock was labeled as angle of PDOF and examined. The absolute angle difference from head-on orientation for the two vehicles in the vehicle-to-vehicle side crash was labeled as orientation angle and also examined.

Table 2. Standing Height of Dummies and US Population[2]

	H-III**	People* (min/mean/max)
95th Male	6' 2"	5'10"/**6'2"**/6'3"
50th Male	5' 9"	5'4"/**5'9"**/5'10"
5th Female	4'11"	4'9"/**4'11"**/5'1"
10 Year-old	4' 6"	4'4"/**4'8"**/5'1"
6 Year-old	3'9"	3'7"/**3'11"**/4'3"
3 Year-old	3'1"	3'0"/**3'3"**/3'6"
1 Year-old	2'5"	2'4"/**2'6"**/2'8"

* Based on stratified 1988-1994 data from the Centers for Disease Control and Prevention/National Center for Health Statistics
** Hybrid III theoretical erect postures (calculated)

Using standing height as a surrogate for size/stature, the NASS/CDS population was segmented into groups. The objective was to define a stratification that best represented the crash population by existing dummies sizes. Since there were gaps and some overlaps between the min/max of the population statistics, the bounds were set up midway between the standing heights of available dummies shown in Table 2. As such, the intervals were [4' 8.5"- 5' 4"], [5' 4"- 5' 11.5"], and [5' 11.5"- 6' 5.5"] for the 5^{th} female, 50^{th} male, and 95^{th} male respectively.

NASS/CDS Overview Results

Side crashes result in 32% of the seriously injured (AIS 3+) occupants in tow-away non-rollover light vehicle crashes in the US (Table 3). Nearside occupants are involved in 49% of the side crashes but they account for 66% of the seriously injured side crash population.

Table 3. NASS/CDS 1995-2001 Annual Estimates Tow-away Non-rollover Light Vehicle Crashes[3]

	All Crashes*	Side	Nearside	Farside
Occupants	4,666, 092	1,306,788	645,113	661,113
(%)		28%	49%	51%
Seriously Injured	94,006	30,094	19,921	10,174
(%)		32%	66%	34%

*Rollovers excluded

When belted occupants in side crashes of modern vehicles of model year 1995 or later are considered, the nearside occupant accounts for 75% or more of the seriously injured as compared to the farside crash occupant (Table 4). Similar proportions are seen when vehicles of all model years are considered and the national estimates are based on larger sample sizes (Table 5). The reduction in the percentage of seriously injured farside occupants relative to nearside occupants in the belted population is consistent with more rigorous analyses of belt effectiveness. In an earlier study by NHTSA, the fatality reduction for 3-point belts was found to be 39% and 58% for farside occupants in side struck passenger cars and LTVs, respectively, compared to 10% and 41% for nearside occupants [10].

Table 4. 1995-2001 NASS/CDS - AIS 3+ Belted Occupants, MY 95+ Struck Vehicle

	Crash Partner					
	pass car		LTV		narrow obj	
Nearside	8,904	80%	6,678	80%	2,469	75%
n	**82**		**100**		**46**	
Farside	2,230	20%	1,704	20%	834	25%
n	**26**		**26**		**20**	

Table 5. 1990-2001 NASS/CDS - AIS 3+ Belted Occupants, All MY Struck Vehicle

	Crash Partner					
	pass car		LTV		narrow obj	
Nearside	50,709	71%	36,547	79%	12,163	76%
n	**470**		**477**		**191**	
Farside	21,047	29%	9,478	21%	3,765	24%
n	**130**		**148**		**68**	

Using simple ratios of the number of seriously injured and killed occupants to total number involved, annual injury and fatality rates for near side crashes relative to all crashes are presented in Table 6. In a nearside crash, an occupant is 30% more at risk of being seriously injured and 58% more at risk of being killed as compared to occupants of all crashes. The lower injury rates observed among reported belt users in the comparisons in Table 6 are consistent with more rigorous analyses of belt effectiveness [10].

Table 6. Serious Injury/Fatality Rates-Annual Estimates NASS/CDS 95-01 Light Vehicles

	All Occ Rates (%)	Belted Rates (%)	Unbelted Rates (%)
All Crashes*	2.4/0.5	1.5/0.3	7/1.7
Near Side	3.1/0.8	2.4/0.6	8.4/2.3

* Rollovers included

Near Side Belted Side Crashes For the Modern Model Year Fleet

Near side crashes, with all objects and light vehicles as crash partners, were studied for struck vehicles of recent model years, i.e. model years 1995 or later (MY 95+) and were compared with similar crashes for struck vehicles of model years 1994 or earlier (MY 94-).

[2] The min/max for adults (age 20+ years) is from any one percentile group considering age, ethnicity and race. The mean is for the groups combined. For children, the min/mean/max are the $5^{th}/50^{th}/95^{th}$ percentiles of the average between boys and girls of the age group irrespective of ethnicity and race.
[3] Tables 2 and 3: First vehicle damage was used when most severe damage was not available, thus allowing the use of cases with un-inspected vehicles.

For nearside seriously injured belted occupants in modern vehicles (MY 95+), chest is the predominant injured body region (52%) followed by head (22%), pelvis (19%) and abdomen (12%) (Figure 8). For the modern vehicles, seriously injured occupants with chest injuries decreased from 66% for the older model years. Modern vehicle AIS 3+ occupants had a slightly lower percentage of serious head injuries and a slightly higher percentage of serious pelvis injuries.

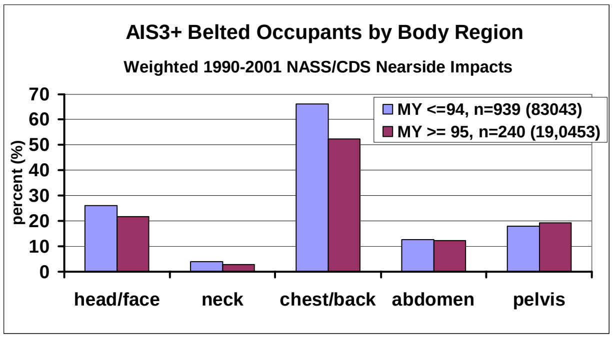

Figure 8. Belted occupants by seriously injured body region in nearside crashes.

When the frequency of serious injuries and standard errors computed by the Sudaan software [11] are considered for MY 95+ vehicles, 39.7% ± 1.73% of the injuries were in the chest, followed by 25% ± 2.5% in the head, 8.4% ± 1.7% in the abdomen, and 11.7% ±3% were in the pelvis respectively. For MY 94- vehicles, 31.4% ± 3.1% of the injuries were in the chest, followed by 21.37% ± 3.1% in the head, 8% ± 1.2% in the abdomen, and 13.2% ±2.2% were in the pelvis respectively. The reduction in the frequency of serious chest injuries for nearside belted occupants in MY95+ vehicles as compared to MY94- vehicles is statistically significant.

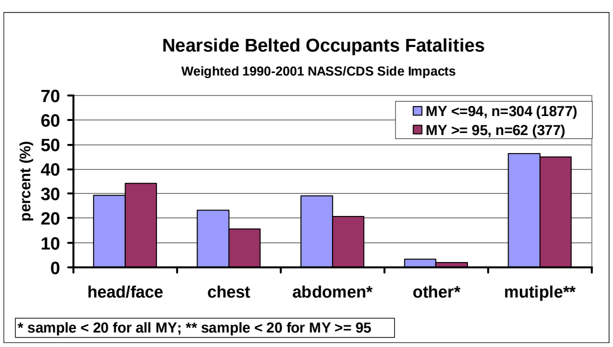

Figure 9. NASS/CDS fatalities in occupants with an injury in a given body region.

In fatal NASS/CDS cases with nearside belted occupants, occupants were categorized by a maximum serious injury (MAIS 3+) in a single body region or in multiple body regions, e.g. AIS 4 in both head and chest (Figure 9). In MY 95+ struck vehicles, occupants with head injury had the highest percentage of fatalities at 34% followed by those with abdominal injury at 21% followed by the chest at 16% (Figure 9).

A similar ranking was seen with MY 94- vehicles. Occupants with an MAIS 3+ in more than one body region had over 45% fatalities for all model years. Fatalities for occupants with chest injuries decreased from 23% to 16%. In contrast, there was an increase from 29% to 34% in fatalities for occupants with head injuries in modern nearside struck vehicles (Figure 9)[4].

The overall fatality rate for seriously injured belted occupants decreased from 27.8% to 17.5% in modern nearside struck vehicles as compared to the older models (Table 7).

Table 7. AIS 3+ Occupant Attributes for Modern Vehicles vs. Older Side Struck Models

	MY 94/earlier	**MY 95/later**
female	50%	55.3%
rear seat	4.1%	6.5%
partial eject	6.5%	5.8%
fatality	27.8%	17.5%

Occupants with a 5^{th} female height grouping increased to 34% of the seriously injured occupants in modern nearside struck vehicles from 20% for the older models while the occupants with a 50^{th} male height grouping decreased from 60% to 45% in the modern vehicles (Figure 10).

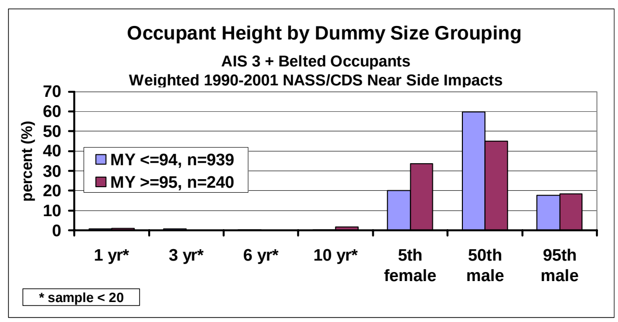

Figure 10. Seriously injured occupants by dummy size height grouping.

For serious nearside head/face injuries, the predominant injuring contacts are the exterior of other vehicle and B-pillar, with the B-pillar being more prominent for the modern side struck vehicles (Table 8). For serious nearside chest injuries, the predominant injuring contact is the side interior followed by the armrest for all model year side struck vehicles (Table 9).

[4] There was also a decrease from 29% to 21% in fatalities for occupants with MAIS 3+ abdominal injuries, but sample size <20

Table 8. Nearside Impacts Head/Face Injuring Contacts by Rank Order (%), AIS 3+ Injuries

MY 94 & earlier		MY 95 & later	
oth veh ext	26	B-pillar	28
B-pillar	19	oth veh ext	20
Roof	12.3	Roof	13
side interior	12	left side*	8
left side	6	oth veh/obj	6

*Sample size < 20

Table 9. Nearside Impacts Chest/Back Injuring Contacts by Rank Order (%), AIS 3+ Injuries

MY 94 & earlier		MY 95 & later	
side interior	63	side interior	62
arm rest	14	arm rest	15
B-pillar	8.5	B-pillar	6
steerng whl	8	belt web/buc*	6
seat/bck supprt*	2	instr pnl+below*	3

*Sample size < 20

There is an increase of median delta-v, vehicle and crash partner weight for seriously injured occupants in modern struck vehicles (Table 10). Median crash conditions are the values below which 50% of the seriously injured occupants are accounted for.

Table 10. Median Crash Conditions for Side Struck Vehicles, AIS 3+ Occupant

MEDIANS	MY 94/earlier	MY 95/later
total delta-v	18 mph	21 mph
lat delta-v	15 mph	17 mph
PDOF	69 deg	60 deg
orientation	80 deg	90 deg
vehicle weight	2800 lbs	3108 lbs
partner weight	3263 lbs	3329 lbs
partner MY	1986	1992

Overview of Crash Partner in FARS

Using FARS data, nearside fatalities in the first two rows of light vehicle side impacts (excluding all rollovers) were examined by crash partner. In 2001 FARS nearside struck MY 95+ vehicles, 21% of fatalities occurred in narrow object crashes and 32% in crashes where a vehicle was struck by an SUV or pickup truck (Figure 11).

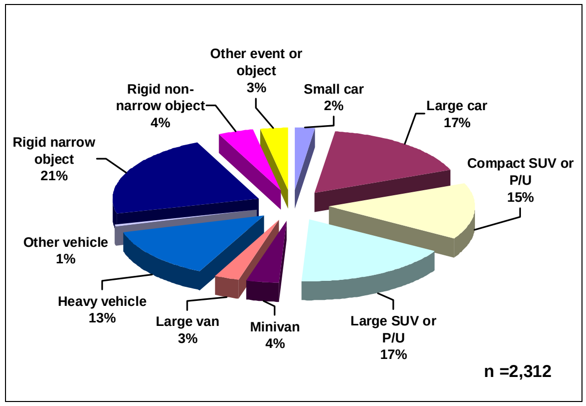

Figure 11. All Occupants: Crash Partner, 2001 FARS Nearside Nonrollover Occupant Fatalities, MY 1995+ Struck Vehicle.

When the belted population is considered, narrow object crashes account for 16% and crashes with a SUV or pickup truck account for 38% of the fatalities (Figure 12).

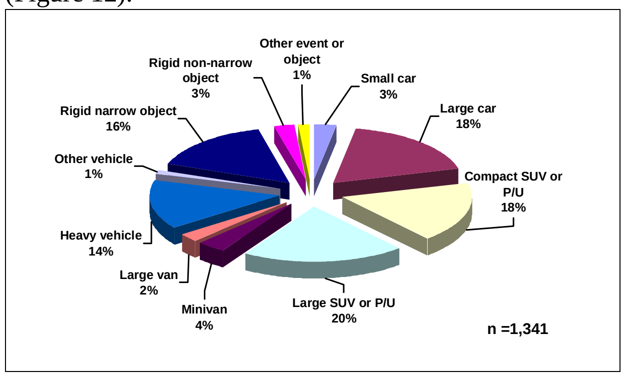

Figure 12. Belted Occupants: Crash Partner, 2001 FARS Nearside Nonrollover Occupant Fatalities, MY 1995+ Struck Vehicle.

A look at the trend of fatalities in FARS vehicle-to-vehicle nearside belted crash subpopulation is shown in Figure 13. In the modern FARS fleet, SUV and pickup trucks, as crash partners, increasingly account for more fatalities in side struck vehicles (54% in 1999 FARS, 65% in 2001 FARS).

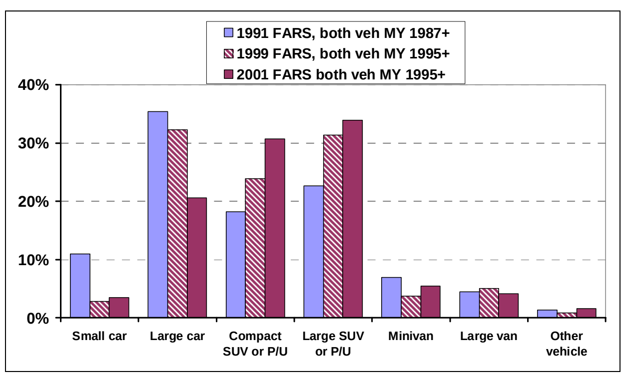

Figure 13. Crash Partner in Vehicle-to-Vehicle Nearside Belted Nonrollover Fatal Crashes.

Overview of Crash Partner in NASS/CDS

Using NASS/CDS national estimates, nearside crashes with passenger cars involved 54% of occupants and resulted in 38% of the seriously injured and 29% of the EFUs. This is in contrast with nearside crashes with LTVs and narrow objects, which involved 26% and 8% of occupants but resulted in 29% and 18% of the seriously injured, and 30% and 23% of the EFUs (Figure 14).

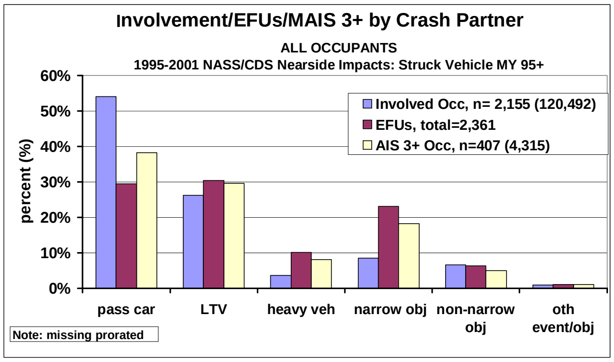

Figure 14. NASS/CDS- All Occupants: Involvement/ EFUs/MAIS3+ by Crash Partner.

When the belted population is considered, nearside crashes with passenger cars, LTVs, and narrow objects account for 43%, 32%, and 12% of the seriously injured and 34%, 35%, and 16% of the EFUs respectively (Figure 15). The reduction in the percentage of seriously injured occupants in narrow object crashes with belted occupants relative to crashes with passenger cars and LTVs is consistent with more rigorous analyses of belt effectiveness. In an earlier study by NHTSA, the fatality reduction for 3-point belts was found to be 21% in fixed objects nearside impacts for side struck passenger cars compared to 12% for crashes with other passenger cars [10].

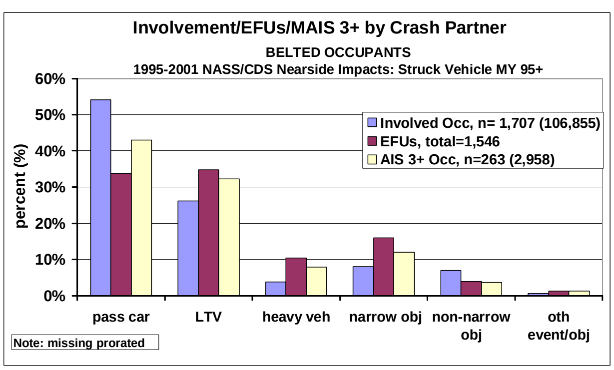

Figure 15. NASS/CDS- Belted Occupants: Involvement/EFUs/MAIS3+ by Crash Partner.

Nearside Belted Side Crashes For the Modern Model Year Fleet by Crash Partner

Nearside crashes with passenger cars, and narrow objects as crash partners were further studied for seriously injured belted occupants and MY95+ struck vehicles, and compared with similar crashes for MY 94- struck vehicles. Chest is the predominant injured body region for the three crash partners (Figures 16-18). Crashes with LTVs and narrow objects had more occupants with serious head injuries for all model years.

For MY 95+ struck vehicles, crashes with passenger cars had a considerable decrease in occupants with chest injuries and in occupants with head injuries, but an increase in occupants with pelvic injuries. Crashes with LTVs also had a considerable decrease in occupants with head injuries and a decrease in occupants with chest and pelvic injuries but an increase in occupants with abdominal injuries. Only narrow object crashes had increases in both occupants with head and occupants with chest injuries in MY 95+ struck vehicles.

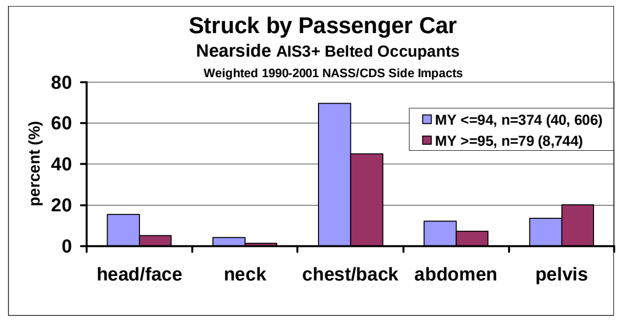

Figure 16. Struck by a passenger car: NASS/CDS seriously injured occupants.

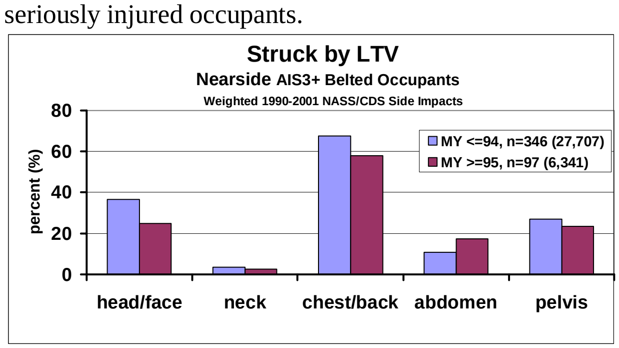

Figure 17. Struck by an LTV: NASS/CDS seriously injured occupants.

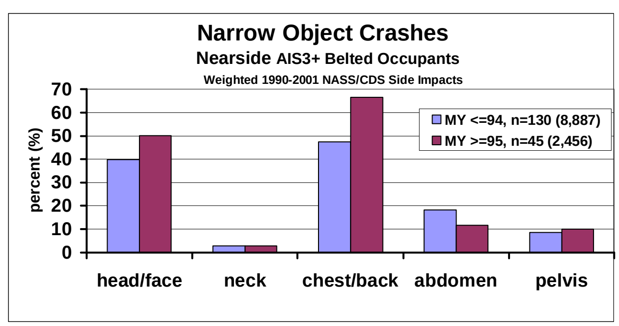

Figure 18. Narrow Object crashes: NASS/CDS seriously injured occupants.

In MY 95+ struck vehicles, fatalities decreased considerably in AIS3+ occupants struck by a passenger car (PC) while they increased for narrow object (NO) crashes relative to the older models (Table 11). For MY 95+ nearside struck vehicles, seriously injured belted occupants are 3 times as likely to die in a crash with an LTV, and 6 times as likely to die in crash with a narrow object when compared to a crash with a passenger car. Partial ejections for occupants in crashes with LTVs and narrow objects are on the order of 10 to 15 times higher than in crashes with passenger cars (Table 12).

Table 11. Fatalities in AIS 3+ Occupants, NASS/CDS 1990-2001 Nearside Crashes

	PC	LTV	NO
belted occ, all MY	21.2	26.6	38.4
belted occ, MY 94 -	24.2	27.4	37.5
belted occ, MY 95 +	7.0	23.2	42.3

Table 12. Partially Ejected AIS 3+ Occupants, NASS/CDS 1990-2001 Nearside Crashes

	PC	LTV	NO
all occ, all MY	5.3	7.6	20
belted occ, all MY	2.1	8.6	16.4
belted occ, MY 94 -	2.4	8.4	16.6
belted occ, MY 95 +	0.9	9.2	15.7

The small size occupants (up to 5' 4" height) increased to about 40% of the seriously injured occupants for all the three crash partners in the modern nearside struck vehicles (Figures 19 and 20).

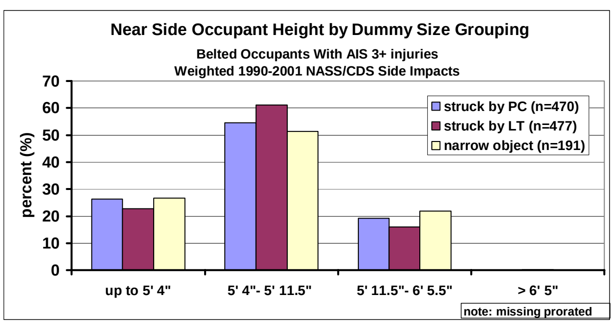

Figure 19. All model years: NASS/CDS seriously injured occupants by height.

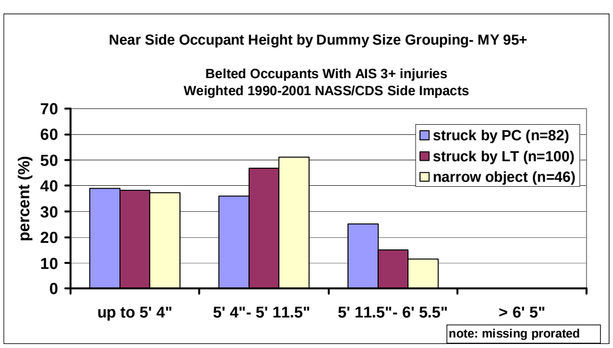

Figure 20. MY 95+: NASS/CDS seriously injured occupants by height.

The percentages of seriously injured versus involved occupants by side crash partner for different size occupants are presented in Figures 21-23. When the ratio of the number of seriously injured occupants relative to the number of occupants involved is considered, the small size occupant is more at risk of serious injury in side impacts irrespective of crash partners. In crashes with passenger cars, the small size occupant is over 220% more likely to be seriously injured then occupants in the 50th male size grouping. In crashes with LTVs and narrow objects, the small size occupant is 34% and 10% more likely to be seriously injured than occupants in the 50th male size grouping. The lowest risk of serious injury is for occupants in the 95th male size grouping in narrow object crashes, followed by occupants in the 50th male grouping in crashes with passenger cars.

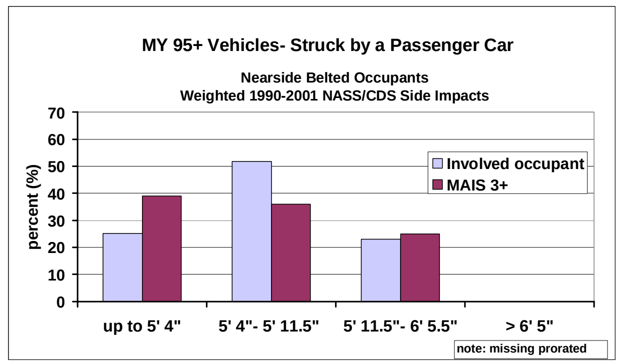

Figure 21. Nearside Occupants in Passenger Car Side Crashes by Dummy Size Groupings: Involved versus Seriously Injured.

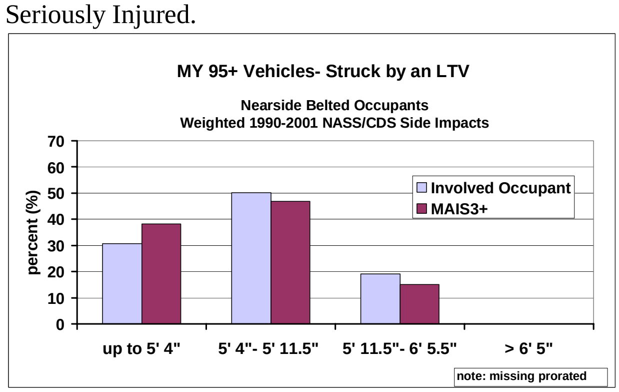

Figure 22. Nearside Occupants in LTV Side Crashes by Dummy Size Groupings: Involved versus Seriously Injured.

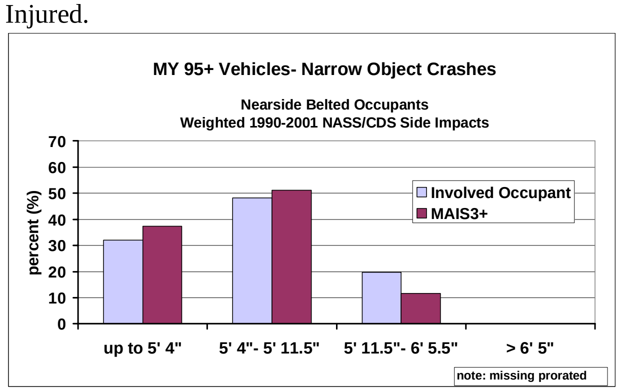

Figure 23. Nearside Occupants in Narrow Object Side Crashes by Dummy Size Groupings: Involved versus Seriously Injured.

For head/face injuries, the predominant injuring contact is the exterior of other vehicle in crashes with LTVs and the B-pillar in crashes with passenger cars and narrow objects (Table 13). For chest injuries, the predominant injuring contact is the side interior for the three crash partners.

Table 13. Nearside Impact Head/Face Injuring Contacts by Rank Order (%), 1990-2001 NASS/CDS Belted Occupants, AIS 3+ Injuries

struck by PC		struck by LTV		narrow object	
B-pillar	23	oth veh ext	43	B-pillar	29
oth veh ext	15	B-pillar	16	Roof	22
Roof	13	side interior	14	left side	15
A-Pillar	13	A-pillar	9	oth object	9
side interior	9	Roof	7.2	A-pillar*	7

*sample size <20

Table 14. Nearside Impact Chest/Back Injuring Contacts by Rank Order (%), 1990-2001 NASS/CDS Belted Occupants, AIS 3+ Injuries

struck by PC		struck by LTV		narrow object	
side interior	55	side interior	67	side interior	57
arm rest	22	steerng whl	13	seat/bck supprt*	15
B-pillar*	13	arm rest	7	steerng whl*	8
belt web/buc*	3	B-pillar	4	instr pnl+below*	5
steerng whl*	2	belt web/buc*	2.4	oth occ*	3

*sample size <20

Median crash conditions for seriously injured occupants are presented in Table 15. In vehicle-to-vehicle crashes, the median delta-v is higher for crashes with LTVs than with passenger cars for all model years. The shift to higher delta-v's in crashes with LTVs is shown in the distributions that are presented for the modern struck vehicles in Figures 24 and 25. While the orientation angle is 90 degrees for both striking LTVs and passenger cars in MY 95+, the PDOF is 60 degrees emphasizing the contribution of the longitudinal component of the delta-v for both crash partners (Figure 25).

Table 15. Median Crash Conditions for Modern Vehicles vs. Older Side Struck Models, MAIS 3+

	struck by PC		struck by LTV	
MEDIANS	**MY 94- n=470**	**MY 95+ n=82**	**MY 94- n=477**	**MY 95+ n=100**
total delta-v	16 mph	18 mph	21 mph	22 mph
lat delta-v	13 mph	14 mph	18 mph	18 mph
PDOF	69 deg	60 deg	70 deg	61 deg
orientation	75 deg	90 deg	90 deg	90 deg
vehicle weight	2998 lbs	3219 lbs	2844 lbs	2998 lbs
partner weight	3064 lbs	3153 lbs	3638 lbs	3968 lbs
partner MY	1986	1993	1988	1992

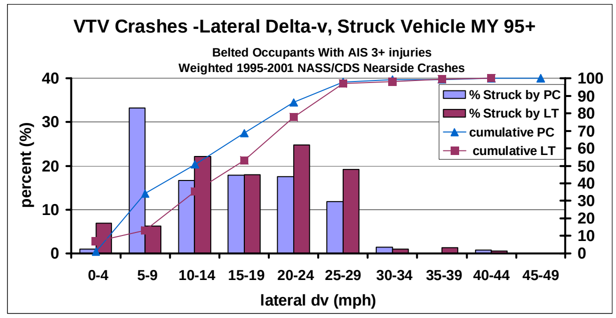

Figure 24

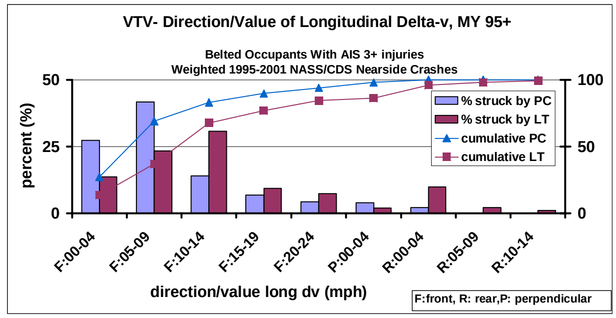

Figure 25

The median curb weight for a striking LTV is 3968 lbs vs. 3153lbs for a striking passenger car for seriously injured occupants in MY 95+ struck vehicles. There is a shift to heavier striking vehicles for the modern fleet as compared to older models years (Figure 26 and 27).

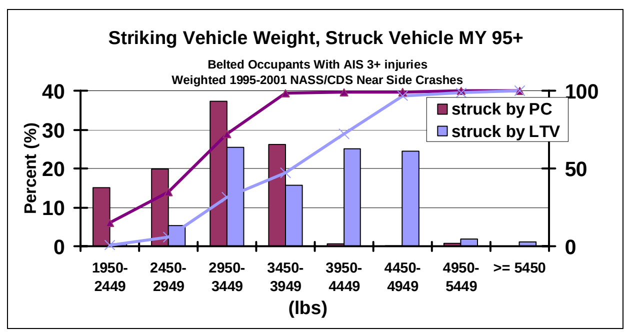

Figure 26

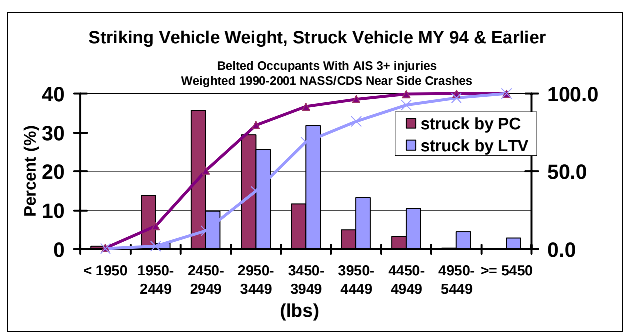

Figure 27

The median delta-v for nearside narrow crashes has increased for MY 95+ (Table 16). The total delta-v distribution is presented for all model years to allow for a larger sample size (Figure 28).

Table 16. Narrow Object Crashes - Median Crash Conditions for Modern vs. Older Models, MAIS 3+

MEDIANS	MY 94- n=191	MY 95+ n=46
total delta-v	20 mph	24 mph
lat delta-v	16 mph	17 mph
PDOF	71 deg	60 deg
vehicle weight	2822 lbs	3108 lbs

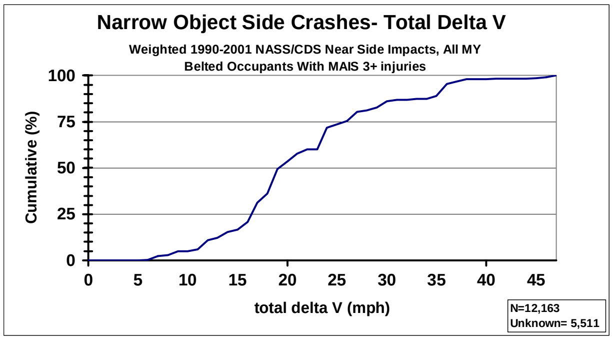

Figure 28

The angle of PDOF distribution shows a wide range of approach angles of the vehicle to the struck narrow object (Figure 29). Forward oblique angles, i.e. 0-85° clockwise or anti-clockwise from 12 o'clock, account for about 68% of the seriously injured occupants while 90° approaches account for only 11% of the seriously injured (Figure 30).

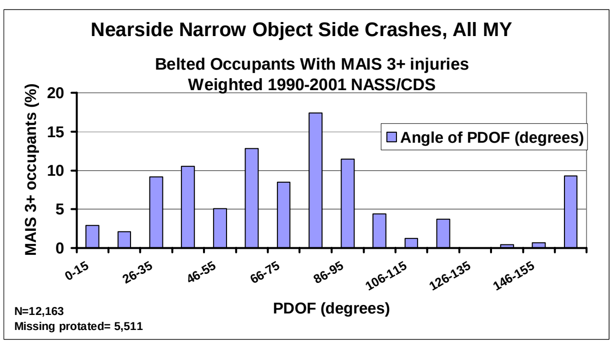

Figure 29

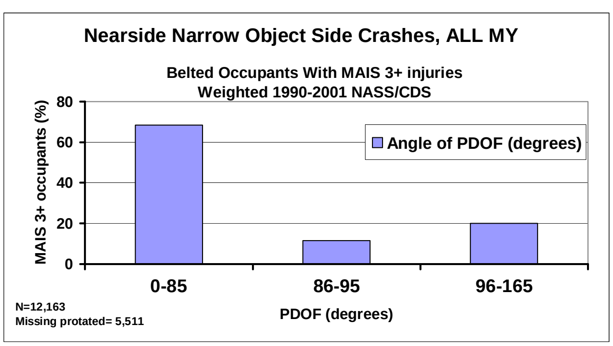

Figure 30

Front Seat Occupant: How Does Stature Affect his/her Nearside Crash Safety?

As shown above, small size occupants account for close to 40% of the seriously injured occupants in near side crashes of modern vehicles. To better understand the safety problem for the front seat nearside crash population, occupant characteristics and injuries were examined for small and large size occupants. Using height as a surrogate for size, two height groupings based on current side impact dummy availability, the 50th percentile male and the 5th percentile female were considered. The assumption was that the crash population height groupings 5' 4" or less and greater than 5' 4" would be best represented by the two existing side impact dummy sizes in advanced crash test procedures. To allow for a larger sample size, all model years were considered.

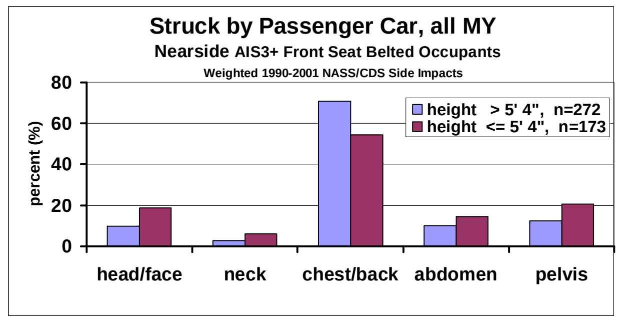

Figure 31

With exception of chest injuries, front seat occupants <= 5' 4" have a higher percentage of serious injuries in the major body regions than those > 5' 4" in crash with passenger cars, LTVs, and narrow objects (Figures 31-33), specifically in the head.

Over 18,000, i.e. 38.4%, of the serious head injuries for the front seat occupant occur in the small size occupants. 49% of those are in crashes in a vehicle struck by an LTV and 34% are in crashes with a passenger car. Over 29,000, i.e. 61.6% of the serious head injuries occur in the large size occupants. 53.5% of those are in crashes with LTVs and 27% are in narrow object crashes.

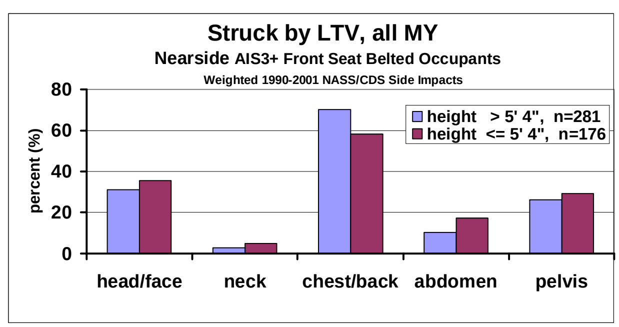

Figure 32

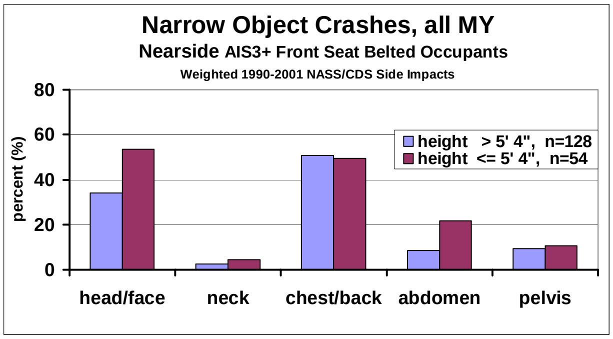

Figure 33

Table 17. Height > 5’ 4”: Head/Face Injuring Contacts (%) for Front Seat Belted AIS 3+ Occupant

struck by PC		struck by LTV		narrow object	
B-pillar	26	oth veh ext	48	B-pillar	32
roof	26	B-pillar	15	left side	22
-		A-pillar	14	Roof	14
-		Roof	9	oth object	9

Table 18. Height <= 5’ 4”: Head/Face Injuring Contacts (%) for Front Seat Belted AIS 3+ Occupant

struck by PC		struck by LTV		narrow object	
oth veh ext*	28	oth veh ext	46	roof*	46
A-Pillar*	23	B-pillar	22	B-pillar*	30
side interior	13	side interior*	11	oth object*	12
B-pillar*	9	roof*	8		

*sample <20

The main head injuring contacts for the large size occupant are the other vehicle exterior and B-pillar in crashes with LTVs and narrow objects (Table 16). The data indicate similar injuring contacts for the small size occupant in crashes with LTVs and passenger cars (Table 17). In addition, the side interior, which includes everything below the window sill in an intruding door structure, is the fourth top injuring contact for serious head injuries for the small size occupants.

When the fatal NASS/CDS cases are considered, a small size seriously injured occupant is twice as likely to die in a narrow object crash than the large size occupant and less likely to die in a crash with a passenger car (Table 18).

Table 19. Front Seat AIS 3+ Belted Occupants, 1990-2001 NASS/CDS Nearside Crashes, all MYs

	ht <= 5' 4"			ht > 5' 4"		
	PC n=173	LTV n=176	NO n=54	PC n=272	LTV n=281	NO n=128
female	87	82	73	43	32	27
partial eject	4	10	16	2	7	15
fatality	17	29	54	22	26	29

In crashes with LTV, the various age groups examined were nearly equally represented in the seriously injured for both small and large occupants (Figure 35).

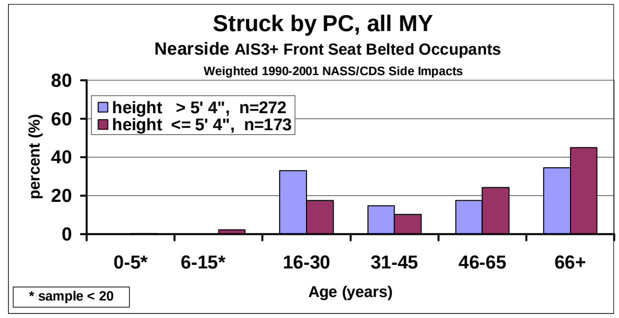

Figure 34

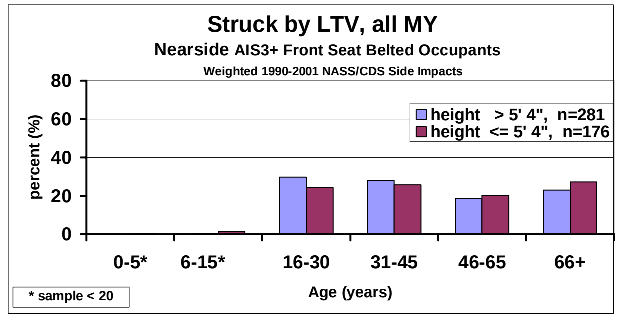

Figure 35

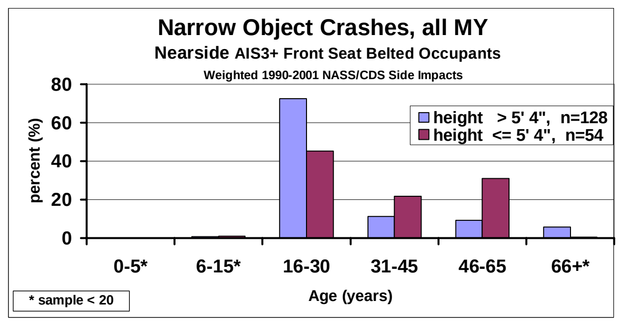

Figure 36

In crashes with passenger cars, the older age occupants make up a larger segment of the seriously injured occupants. In such crashes, 45% of the seriously injured small occupants and 35% of the large occupants are over 66 years old (Figures 34). In contrast, in narrow objects crashes, 45% and 73% of the seriously injured small and large occupants are between 16 and 30 years of age (Figure 36).

NASS/CDS Nearside vs. Farside Seriously Injured Occupants

Although farside occupants represent 25% or less of the seriously injured in belted side crashes of modern side struck vehicles, it is worthwhile to examine their injuries and injuring contacts. This would enable the assessment of current/future countermeasures that may have the potential to improve farside crash safety protection. To allow for a larger sample size for farside occupants, all model year struck vehicles were considered.

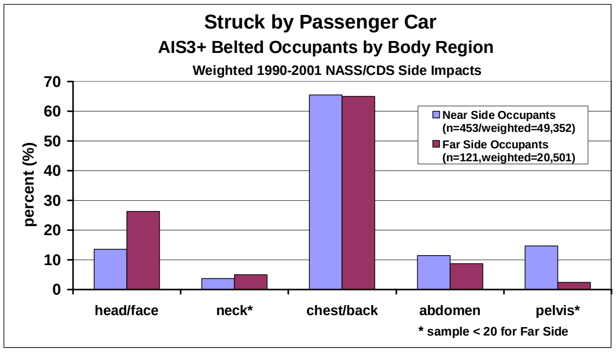

Figure 37

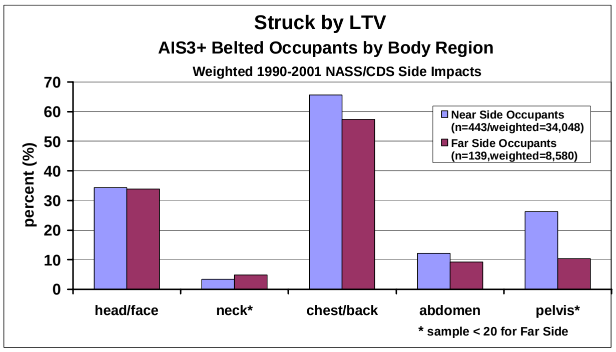

Figure 38

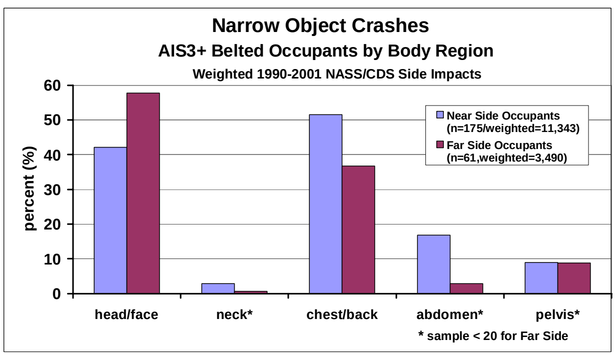

Figure 39

When compared to nearside occupants, chest injuries are also predominant in AIS3+ farside occupants in crashes with passenger cars and LTVs (Figures 37-39). Head injuries are predominant for farside AIS 3+ occupants in narrow object crashes and are increased in crashes with passenger cars. Pelvis injuries are decreased for farside AIS 3+ occupants in crashes with passenger cars and LTVs.

Table 7. Farside Impact Head/Face Injuring Contacts by Rank Order (%), 1990-2001 NASS/CDS Belted Occupants

struck by PC		**struck by LTV**		**narrow object**	
A-Pillar*	30	side interior	43	Roof	29
side interior	14	non contact*	11	B-pillar*	18
head restr*	13	str panel+belov	9	side interior*	12
Mirror*	12	Roof*	8	oth object*	11
instr pnl+bel*	8	B-pillar*	7.8	instr pnl+bel*	7

***sample size <20**

Table 20. Farside Impact Chest/Back Injuring Contacts by Rank Order (%), 1990-2001 NASS/CDS Belted Occupants

struck by PC		**struck by LTV**		**narrow object**	
belt web/buc	72	belt web/buc	36	seat/bck supprt*	50
seat/bck supprt*	10	oth occ*	12	side interior*	17
side interior	5	instr pnl+below*	11	belt web/buc*	7
front air bag*	4	side interior	9	instr pnl+bel*	7
instr pnl+bel*	3	seat/bck supprt*	8	steerng whl*	5

***sample size <20**

The side interior is the dominant injuring contact for serious head injuries for AIS 3+ farside occupants followed by the roof (Table 18). The belt restraint webbing/buckle is the dominant injuring contact for serious chest injuries for AIS 3+ farside (Table 19).

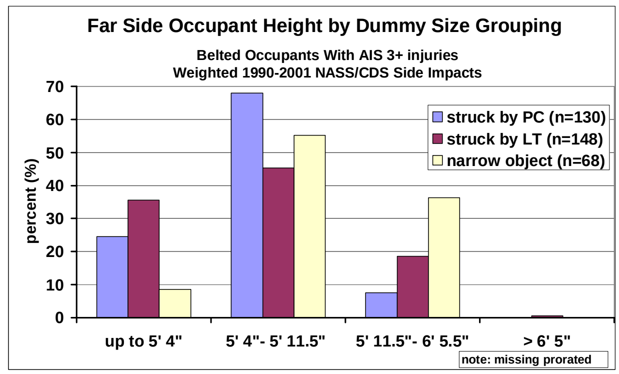

Figure 40.

The small size occupants (up to 5' 4" height) make up 25%, 36%, and 9% of the seriously injured occupants for AIS 3+ belted farside occupants in crashes with passenger, LTVs, and narrow objects (Figure 40).

Overview of Rear Seat Occupants Side Crash Safety

Mainly because of lower occupancy rates, rear seat (second row in this analysis) occupants make up a small percentage of the seriously injured in side crashes (Table 19). In nearside crashes of modern vehicles, rear occupants make up 7.3%, 10.2% and 4.4% of those involved in crashes with passenger cars, LTVs and narrow objects and account for 5.6%, 1.4% and 14.2% of the seriously injured in these crashes. Although they make up a small percentage of the seriously injured population, it is important to examine the rear seat side crash safety problem, specifically in light of the NHTSA policy and accepted safety practice that children aged 12 years and younger be seated in the rear seat. To allow for a larger sample size, especially for the farside rear seat population, both belted and unbelted occupants, and moderate injuries (AIS 2+) were considered in side crashes involving light vehicles.

Table 21. Rear Seat AIS 3+ Occupants Rear Seat Occupancy (%), NASS/CDS 1990-2001 Nearside Crashes **(Farside)**

	PC	LTV	NO
all occ, all MY	7.1**(3.4)**	7.8 **(5)**	10.8 **(7.7)**
belted occ, all MY	3.3 **(1.2)**	3.5 **(2.5)**	8.6 **(3.5)**
belted occ, MY 95+	5.6	1.4	14.2
belted occ, MY 94 -	2.8	3.9	7.2

Head injuries are predominant for moderately injured rear seat occupants specifically for the farside at 65% (Figures 41 and 42). For the nearside rear seat occupants, chest is second main injured body region followed by the abdomen for both the seriously and moderately injured. Back injuries are over 39% of the moderate chest/back injuries for nearside rear occupants, while they make up less than 1% of the serious chest/back injuries.

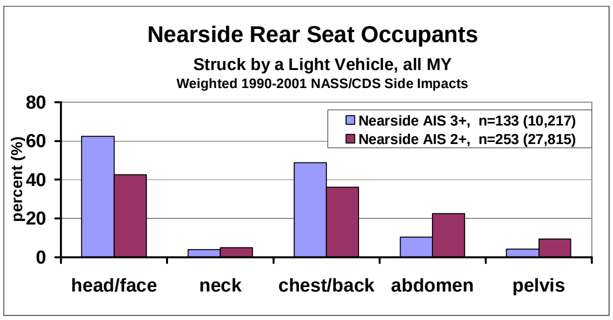

Figure 41

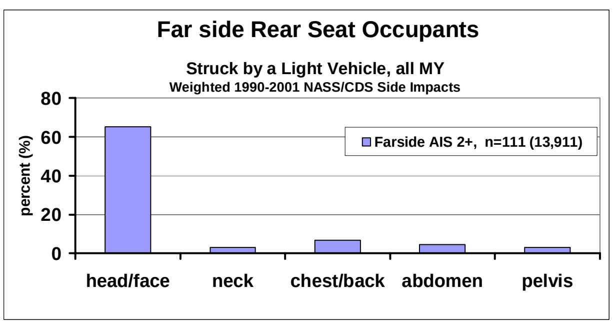

Figure 42

The side interior is the dominant injuring contact for head injuries for AIS 2+ rear seat nearside occupants followed by the B-pillar (Table 22).

Table 22. Rear Seat AIS 2+ Occupants, Head/Face Injuring Contacts (%) – Side Crashes 1990-2001

Nearside		Farside	
B-pillar	27	right side*	37
side interior	23	side interior	25
roof	12	seat bck sppt*	9
right side	8	B-pillar*	8
other pillar	8	roof*	6
oth veh ext*	6		

*Sample<20

For the moderate (AIS 2+) and serious (AIS 3+) nearside chest injuries, the predominant injuring contact is the side interior surface at 91% and 75% respectively.

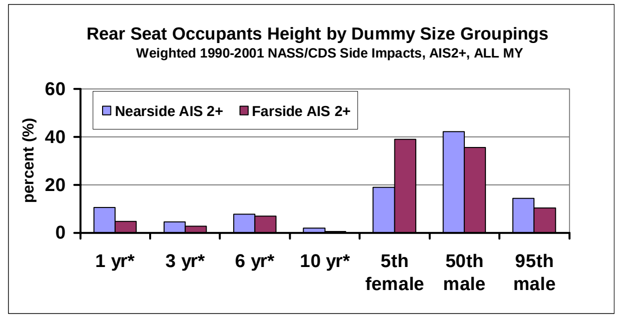

Figure 43

Up to the 5th percentile female height grouping make up 43% and 54% of the occupants for AIS 2+ nearside and farside rear seat occupants (Figure 43). As a single grouping, the 50th male makes up 42% and 36% of AIS 2+ nearside and farside rear seat occupants, and the 5th percentile female grouping makes up 19% and 39% of those populations.

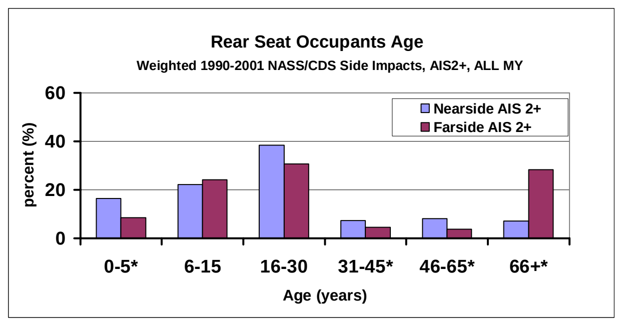

Figure 44

The majority of the AIS 2+ rear seat occupants are under 30 years of age with exception of 28% of the farside occupants are over 66 years old (Figure 44).

Side Crashes and Rollover: A Perspective from FARS and GES

In 2001, 37% of the LTV side crash fatalities and 18% of side crash injuries were in a crash in which a rollover occurred. This is compared to 12% of fatalities and 5% of injuries in side struck passenger cars (Figures 45 and 46). Around 32% of the LTV rollover fatalities occurred in side crashes where the rollover was a subsequent event. Advanced countermeasures and inflatable restraints designed for nearside crash protection may have potential safety benefits in crashes involving side struck LTVs with rollover occurring as a subsequent event.

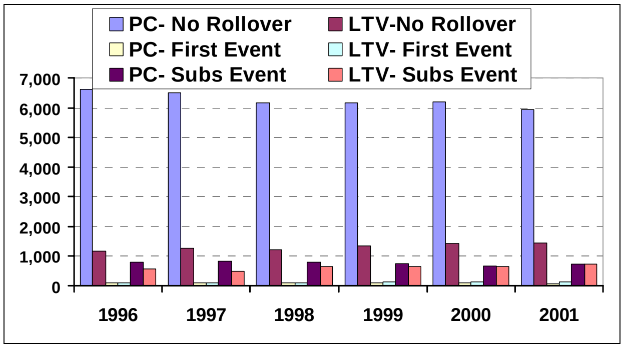

Figure 45. Fatalities in light passenger vehicles with an initial side impact by vehicle type and rollover occurrence, FARS 1996-2001.

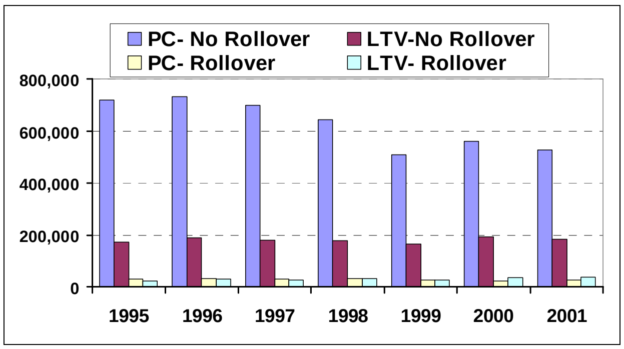

Figure 46. Estimate of occupants injured in light vehicles with an initial side impact by vehicle type and rollover occurrence, GES 1995-2001.

Overview of LTV Side Crash Safety

As part of assessing the future US side crash safety problem, it is necessary to study the side crash safety of the growing LTV population, and to investigate opportunities to improve their side crash protection.

Side struck LTV occupants accounted for 25% of the fatalities and an estimated 29% of injuries in light vehicle side impact on US Roads (2001 FARS and GES). This represents an increase from 19% of the fatalities and 21% of the injuries in 1995. The LTV side impact safety is still small relative to the population of LTV currently on US roads (38.4% in 2001).

To get an indication of the current safety problem by crash partner and have a reasonable population size, nearside nonrollover fatalities in side struck LTVs of model years 90 or later (MY 90+) were examined. In 2001, 24% of the fatalities occurred in narrow object crashes and 27% in crashes where an LTV is struck by another SUV or pickup truck (Figure 47). For the belted LTV fatalities, 18% occurred in narrow object crashes and 35% occurred in a crash by another SUV or pickup truck.

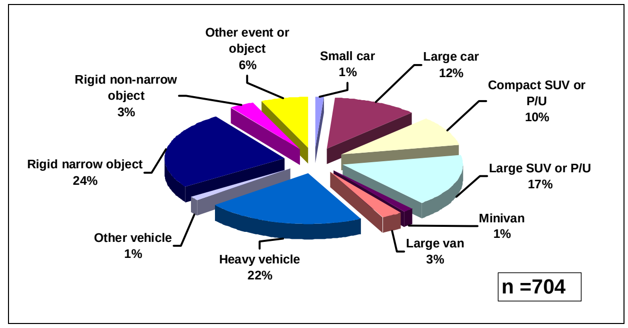

Figure 47. Crash Partner, 2001 FARS Nearside Nonrollover Occupant Fatalities, MY 1990+ Side Struck Light Truck.

In NASS/CDS, for MY 90+ nearside struck LTVs with all occupants (belted and unbelted), crashes with passenger cars, other LTVs, and narrow objects, accounted for 22%, 26%, and 17% of the seriously injured occupants, respectively. Heavy vehicle crashes accounted for 34% of the seriously injured occupants in side struck LTVs as compared to only 10% for all side struck vehicles.

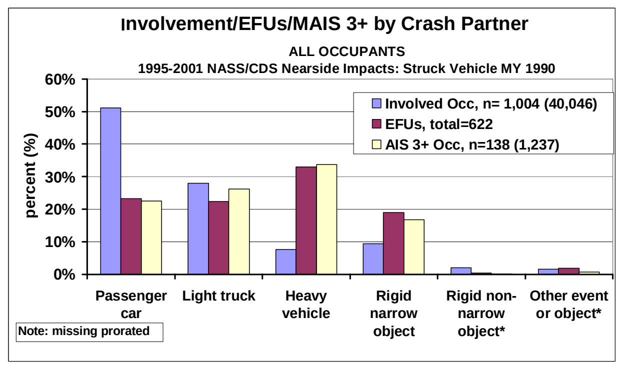

Figure 48

Nearside struck LTVs have a lower percentage of AIS 3+ occupants with chest injuries as compared to all side struck light vehicles (i.e. PCs and LTVs together as the struck population) except in crashes with narrow objects. They have a similar increase of occupants with head injuries in crashes with narrow objects and other LTVs (Figure 49). They have a higher percentage of AIS 3+ occupants with serious pelvic injuries (36%) in crashes with other LTVs.

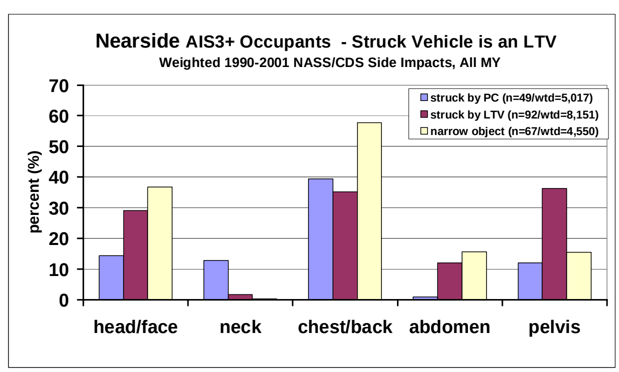

Figure 49

Head injuries are over 24% (9965) of the serious injuries for all occupants (belted and unbelted) in MY 90+ nearside struck LTVs. The main injuring contacts for serious head injury are the A-pillar, roof, and other vehicle exterior or object accounting for 22%, 20%, and 14% of the serious head injuries respectively. For LTVs struck by another LTV, the main injuring contacts are the roof followed by the other vehicle exterior (Table 23). For LTVs in narrow object nearside crashes, the main injuring contacts are the A-pillar followed by the roof and the narrow object itself.

Table 23. Side-struck LTV Head/Face Injuring Contacts (%) – Near Side 90-01, AIS 3+, All MY

struck by LTV		narrow object	
roof	20	A-pillar	40
oth veh ext	14	roof	21
B-pillar*	13	oth veh/obj	12

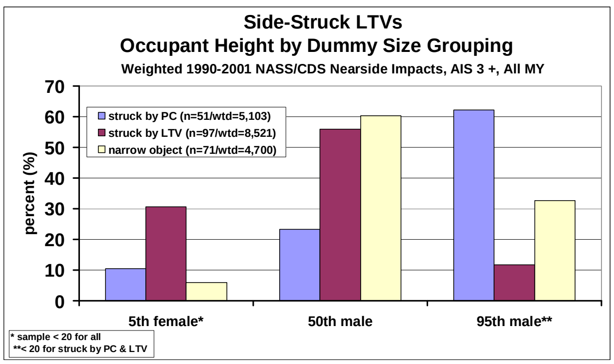

Figure 50

Side struck crash condition medians are similar to those all side struck light vehicles with exception of increased struck vehicle and partner weights (Tables 15, 16, and 24).

Table 24. Crash Conditions for Side-struck, 1990-2001 NASS/CDS, All MY

MEDIANS	PC n=51	LTV n=97	NO n=71
total delta-v	15 mph	18 mph	19 mph
lat delta-v	13 mph	15 mph	17 mph
PDOF	69 deg	70 deg	60 deg
orientation	90 deg	85 deg	-
vehicle weight	3990 lbs	3351 lbs	3616 lbs
partner weight	3291 lbs	4145 lbs	-
partner MY	1990	1990	-

FINDINGS

Modern US Fleet

- The LTV population has grown to approximately 40% of light vehicles in the US and is projected to continue growth based on current sales data.
- Thorax and head air bag systems are being introduced rapidly in the US fleet but their installation rates are currently low. They provide improved chest protection for a 50th percentile male in crashes represented by current FMVSS 214 and improved head protection for a 50th percentile male in crashes represented by current FMVSS 201.

Near Side Crashes

- Near side crashes have higher serious injury and fatality risks as compared to all crashes.
- Nearside safety problem is three times the farside safety problem for belted occupants in the modern fleet (MY 95+ light vehicles).
- Nearside crashes with passenger cars, LTVs, and narrow objects resulted in 38%, 29% and 18% of the seriously injured occupants, and 29%, 30% and 23% of the equivalent fatality units.
- A nearside occupant is three times more likely to be seriously injured in crashes with narrow objects and 1.6 times in crashes with LTVs as compared to crashes with passenger cars.
- In 2001, 37% of side struck LTV fatalities and 18% of injuries were in crashes in which a rollover occurred. This is compared to 12% of fatalities and 5% injuries in side struck passenger cars. Around 32% of the LTV rollover fatalities occurred in side crashes where the rollover was a subsequent event.

Injured Body Regions

- For nearside seriously injured belted occupants in modern vehicles (model years 95 and later), chest is the predominant injured body region (52%) followed by head (22%), pelvis (19%) and abdomen (12%).
- Nearside occupants with serious chest injuries decreased from 66% in older side struck models to 52% in the modern side struck vehicles. The reduction is from 70% to 45% for crashes in which the striking vehicle is a passenger cars.
- There are more occupants with serious head injuries in side crashes with LTVs and narrow objects than crashes with passenger cars in both modern and older vehicles (25% and 50% for LTV and narrow objects vs. 5% for passenger car crashes in modern side struck vehicles).
- There are 18% of occupants with serious abdominal injuries in side crashes with LTVs as compared to 7% in crashes with passenger cars in modern vehicles.
- There is an increase in occupants with serious pelvic injuries from 14% to 20% in nearside crashes with passenger cars in the modern fleet, in contrast with a decrease in the other main body regions, i.e. head, chest, and abdominal injuries.

- Head injuries are predominant for moderately injured rear seat occupants, specifically for the farside at 65%. For the nearside rear seat occupants, chest is second main injured body region followed by the abdomen for both the seriously and moderately injured.

Fatalities and Fatality Risk

- Modern fleet occupants with serious head injury (MAIS 3+) had the highest percentage of fatalities at 34% followed by those with injury in the abdomen at 21%, and in the chest at 16%.
- The overall fatality rate for seriously injured belted occupants decreased from 27.8% to 17.5% in modern nearside struck vehicles as compared to the older models but increased from 29% to 34% for those with serious head injuries.
- For side crashes with passenger cars, the fatality rate for seriously injured belted occupants decreased from 21.2% to 7% as compared to a slight decrease from 26.6% to 23.2% in crashes with LTVs, and an increase from 38.4% to 42.3% in narrow objects crashes in modern vehicles.
- In 2001 FARS nearside struck modern vehicles, 21% of fatalities occurred in narrow object crashes and 32% in crashes where a vehicle was struck by an SUV or pickup truck.
- In 2001 FARS modern fleet, MY 95+ SUVs and pickup trucks, as crash partners, accounted for 65% of the fatalities in vehicle-to-vehicle side crashes (2001 FARS).

Occupant Size

- In the modern fleet, the small size occupant (up to 5' 4" height) is more at risk of serious injury in side impacts irrespective of crash partners. In crashes with passenger cars, LTVs, and narrow objects, the small size occupant is over 220%, 34%, and 10% more likely to be seriously injured, respectively, than an occupant in the 50th male size grouping.

- Occupants in the 5th female height grouping, [4' 8.5"- 5' 4"], increased from 20% to 34% of the seriously injured in modern nearside struck vehicles while those in the 50th male height grouping, [5' 4"- 5' 11.5"], decreased from 60% to 45%.

- With exception of the chest, small size occupant in the front seat have a higher percentage of serious injuries in the major body regions in crashes with passenger cars, LTVs, and narrow objects, specifically in the head.

- Over 18,000, i.e. 38.4%, of the serious head injuries for the front seat occupant occur to small size occupants. 49% of those are in crashes in a vehicle struck by an LTV and 34% are in crashes with a passenger car.

- Over 29,000, i.e. 61.6% of the serious head injuries for the front seat occupant occur to large size occupants. 53.5% of those are in crashes with LTVs and 27% are in narrow object crashes.

Injuring Contacts

- The main head injuring contacts for both the small and the large size front seat occupant are the other vehicle exterior and B-pillar in crashes with LTVs and narrow objects.

- The side interior, which includes everything below the window sill in an intruding door structure, is the fourth top injuring contact for serious head injuries for small size occupants.

- The side interior is the dominant injuring contact for head injuries for AIS 2+ rear seat occupants.

- The predominant injuring contacts for serious head injury in near side struck LTVs are the A-pillar followed by the roof which is probably attributed to structural collapse in the LTV side structure and roof in those crashes.

Crash Conditions

- In vehicle-to-vehicle crashes with seriously injured occupants, the median delta-v is higher for crashes with LTVs than with passenger cars for all model years. Crashes with striking LTVs having a lateral delta-v of 18 mph or higher account for more than 50 % of AIS 3+ occupants as compared to 14 mph for crashes with passenger cars in the modern fleet.
- The median curb weight for a striking LTV is 3968 lbs vs. 3153 lbs for a striking passenger car for seriously injured occupants in the modern struck vehicles.
- While the orientation angle is 90 degrees for both striking LTVs and passenger cars in the modern crash fleet, the PDOF is 60 degrees emphasizing the contribution of the longitudinal component of the delta-v for both crash partners.
- Crashes with delta-v 20 mph or higher result in around half of the seriously injured occupants in narrow object nearside crashes. Frontal oblique crashes, i.e. at a principle direction of force 0-85° clockwise or anti-clockwise from 12 o'clock, account for about 68% of the seriously injured occupants in narrow object crashes while crashes with 90° approaches account for only 11% of the seriously injured occupants.

DISCUSSION: MOTIVATION FOR UPGRADED TEST PROCEDURES

As outlined above, even after full implementation of FMVSS 214, the remaining side impact safety problem is considerable.

Benefits of FMVSS 214 - It worth noting that for the crash condition best represented by dynamic FMVSS 214, nearside crashes with passenger cars, there is a considerable reduction in fatality rates and serious chest injuries in the modern side struck vehicles. Since FMVSS 214 mandated a minimum of 10%, 25%, 40%, and full compliance of vehicle model years 1994, 1995, 1996, and 1997, respectively, of vehicles sold in the US, these safety gains may be attributed in part to the US side impact standard.

Improve Protection for Different Size Occupants- In order to provide better crash protection for all segments of the US motoring population, specifically the small size occupant, the 5^{th} percentile side impact dummy, SIDIIs [12], is being evaluated in current and any potential higher severity crash test configurations. Advanced and different size side impact dummies will be evaluated as those become available**.**

Improve Protection for Multiple Body Regions- To provide improved and added measurement capabilities for injury assessment for occupant head, chest, abdomen and pelvis, the ES-2 [13], an upgrade of EUROSID-1, the side impact dummy of the European Union side impact regulation, is being evaluated.

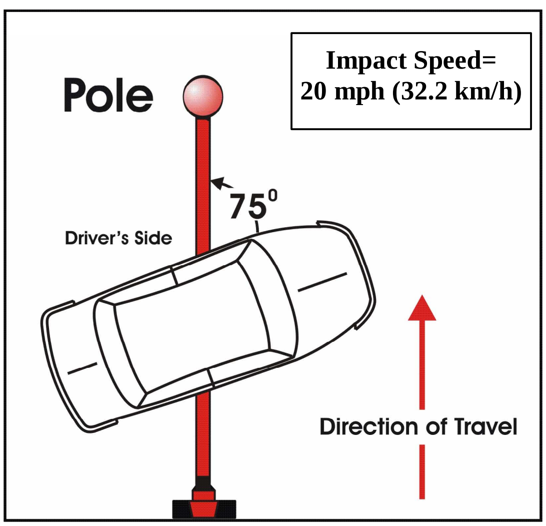

Figure 51. New oblique side pole test configuration

To fully address head protection and improve chest protection, a comprehensive side impact pole test with both 50^{th} male and 5^{th} female side impact dummies is being developed. The new test procedure is intended to simulate real world side crashes with narrow objects such as trees and poles and provides a performance test to promote advanced countermeasures for head and chest protection in higher severity side crashes (Figure 51).

Improve Protection with an Updated Crash Partner-
To provide self-protection in a side crash environment where the injuring crash partner is increasingly an SUV or a pickup truck, research of the FMVSS 214 movable deformable barrier to be more representative of modern striking LTVs is planned. Assessment of countermeasures developed for a pole test requirement and advances in the area of vehicle compatibility and aggressivity will be taken into consideration.

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