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NHTSA's Vehicle Compatibility Research Program

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ABSTRACT
The National Highway Traffic Safety Administration (NHTSA) is conducting a research program to investigate the crash compatibility of passenger cars, light trucks and vans (LTV's) in vehicle-to-vehicle collisions. NHTSA has conducted a series of eight full-scale vehicle-to-vehicle crash tests to evaluate vehicle compatibility issues. Tests were conducted using four bullet vehicles representing different vehicle classes striking a mid-size sedan in both side and oblique frontal crash configurations. The test results show a good correlation between vehicle aggressivity metrics and injury parameters measured in the struck car for the frontal offset tests, but not for the side impact tests.

INTRODUCTION

The National Highway Traffic Safety Administration (NHTSA) is conducting a research program to investigate the crash compatibility of passenger cars, light trucks and vans (LTV's) in vehicle-to-vehicle collisions. The compatibility of a vehicle is a combination of its crashworthiness and its aggressivity when involved in crashes with other members of the vehicle fleet. While crashworthiness focuses on the capability of a vehicle to protect its occupants in a collision, aggressivity is measured in terms of the casualties to occupants of the other vehicle involved in the collision. Improvements in crash compatibility may require improvements in crashworthiness coupled with simultaneous reductions in aggressivity.

NHTSA has recently conducted several studies evaluating the compatibility of LTV's and cars in vehicle-to-vehicle collisions [1,2]. These studies evaluated multi-vehicle crashes reported in the Fatality Analysis Reporting System / General Estimates System (FARS/GES) and evaluated the struck driver fatalities per crash involvement of the subject vehicle. This aggressivity metric has shown an incompatibility between cars and all categories of LTV's. A disproportionate number of the fatalities in LTV-to-car crashes are incurred by the car occupants. While the introduction of newer safety countermeasures (e.g., air bags) may improve compatibility, the incompatibility still exists even when newer model vehicles, 1990 model year or later, are considered.

TEST PROGRAM

In order to demonstrate and better understand the nature of compatibility issues within the U. S. Fleet, and the LTV aggressivity problem in particular, NHTSA has conducted a series of vehicle-to-vehicle crash tests. In the test series, a mid-size sedan, a 1997 Honda Accord, was impacted in both side and frontal crash tests by a series of four vehicles, (1) a small pickup, (2) a sport utility vehicle, (3) a minivan, and (4) another mid-size car. The vehicle categories were selected to represent a variety of different potential aggressivity characteristics: mass, front profile, and vehicle stiffness. The vehicles selected were a 1998 Chevrolet S-10 pickup, a 1997 Ford Explorer, a 1997 Dodge Caravan, and a 1996 Chevrolet Lumina. The specific vehicles were selected due to high sales and the availability of finite element models. It is intended to use finite element models to study mitigation concepts for vehicle aggressivity and to evaluate additional crash configurations.

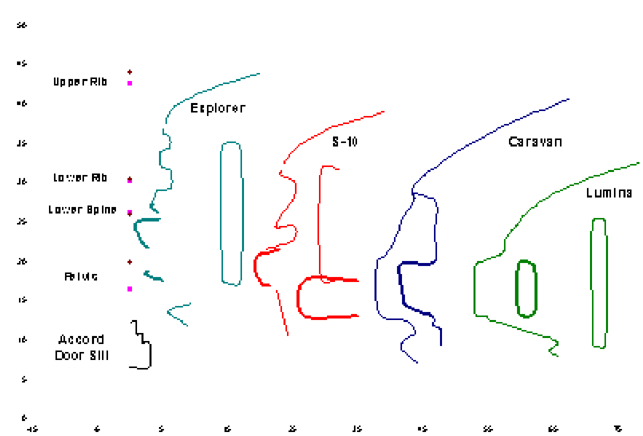

Figure 1 - Front Profile measurements for bullet vehicles

Figure 1 shows the front profiles for the four bullet vehicles in this test series. The striking vehicles represent a significant range in bumper and hood heights for the striking vehicles. Also shown in Figure 1 are the relative height of the Accord door sill for the side impact tests and the heights of the SID sensors. Figure 2 shows the stiffness profiles measured from NCAP testing of the vehicles. For these plots the force was taken from the load cell barriers and the left rear seat accelerometer was used to measure the displacement. Not surprisingly the Ford Explorer has the stiffest force deflection profile and the Chevrolet Lumina has the softest.

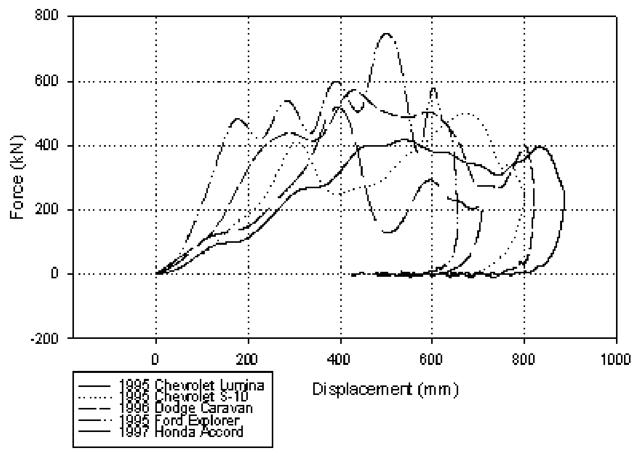

Figure 2 - Stiffness data for test vehicles

SIDE IMPACT TESTING

The four side impact tests were conducted using the FMVSS 214 test protocol, where the bullet vehicle replaces the moving deformable barrier. The bullet vehicles were crabbed 27 degrees and run at 53 kmph. The vehicles were modified as shown in Figure 3. The vehicle test weights are shown in Table 1 below.

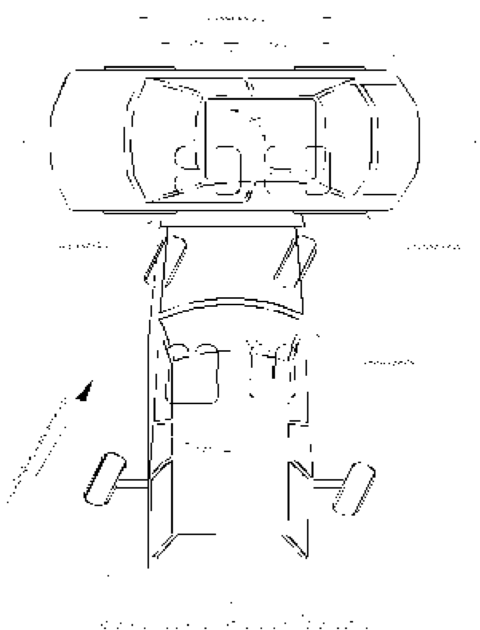

Figure 3 - Side Impact Test Configuration

The tests were conducted with a 50th percentile HIII dummy in the driver seat of the bullet vehicle. A 5th percentile female dummy was used in the right-front passenger seat of the bullet vehicle. Two SID/HIII dummies were placed in the driver and left rear seating positions of the target vehicle. The injury criteria for the side impact tests are shown in Tables 3 and 4. For the occupants in the striking vehicle, the injury criteria are generally very low. In contrast, all of the drivers in the struck vehicles had thoracic trauma index, TTI, values above the threshold for injury. Figure 4 plots the normalized injury values for the driver of the struck vehicle. The injury measures for the struck driver do not show a strong correlation with the weight of the striking vehicle.

Table 1 - Side Impact Vehicle Weights

NHTSA Test Number	Striking Vehicle	Test Weight kg	Accord Test Weight kg
2917	1998 Chevrolet S-10 Pickup	1655	1533
2919	1995 Chevrolet Lumina	1806	1522
2918	1997 Dodge Caravan	2073	1526
2916	1997 Ford Explorer	2123	1550

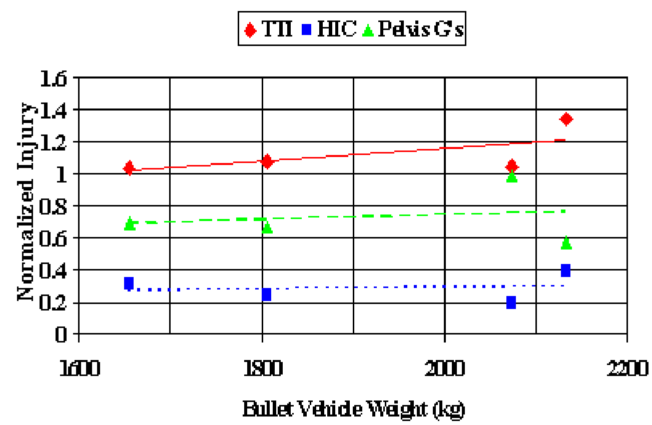

Figure 4 - Injury Measurements for the Driver of the target vehicle.

To look at this another way, the aggressivity metric defined in reference 1 is used instead of vehicle weight.

$$Aggressivity = \frac{\text{Driver Fatalities in collision partner}}{\text{Number of Crashes of subject vehicle}}$$

Figure 5 shows the comparison between the normalized injury and the aggressivity metric for the appropriate vehicle categories measured by FARS/GES 1991-1994 data. The aggressivity metrics from reference 1 are repeated in table 2. Figure 4 does not show as strong a correlation between the injury measures of the target vehicle and the aggressivity metric as would have been expected from the analysis of FARS Data[1]. Additional research is required to understand the high aggressivity metrics observed in FARS.

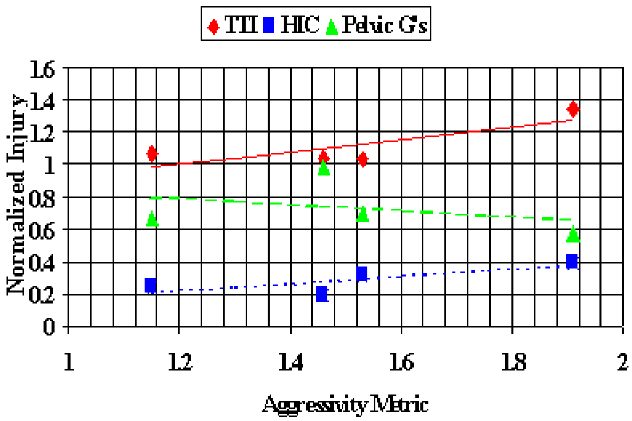

Figure 5 - Injury Measurements for the Driver of the target vehicle

Table 2 - Aggressivity Metrics

Vehicle Category	Struck Driver Fatalities per 1000 Police Reported Crashes
Full Size Van	2.47
Full Size Pickups	2.31
Sports Utility Vehicles	1.91
Small Pickups	1.53
Minivans	1.46
Large Cars	1.15
Mid-size Cars	0.7
Compact Cars	0.58
Subcompact Cars	0.45

OBLIQUE OFFSET TESTING

The frontal oblique tests series was conducted using a test procedure developed under NHTSA's Advanced Frontal Offset Research Program[3]. The test configuration shown in Figure 6. Both vehicles were moving at approximately 56 kmph with the Accord being struck on the left front side. At impact, the left side of the striking vehicle aligns with the center of the front of the Accord. In all tests, both vehicles used a Hybrid III 50th percentile dummy in the driver position, and a Hybrid III 5th percentile female dummy in the right front passenger seating position. All of the dummies were belted and the air bags were active. The vehicle test weights are shown in Table 3 below.

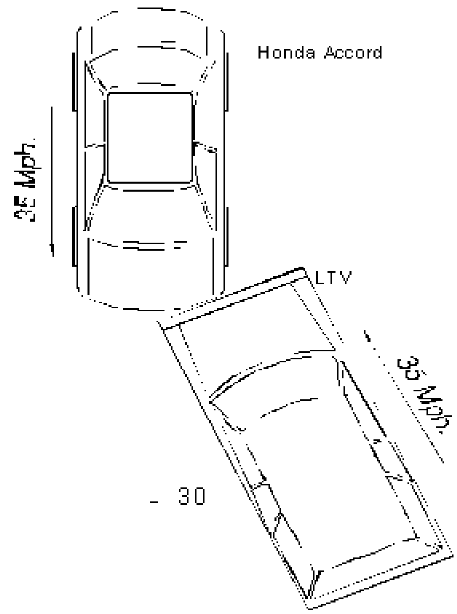

Figure 6 - Oblique Offset Test Configuration

Table 3 - Oblique Offset Vehicle Weights

NHTSA Test Number	Striking Vehicle	Test Weight kg	Accord Test Weight kg
2923	1998 Chevrolet S-10 Pickup	1652	1522
2924	1996 Chevrolet Lumina	1793	1523
2915	1997 Dodge Caravan	1985	1521
2914	1997 Ford Explorer	2065	1523

The measured injury criteria are shown in Tables 6 and 7. With the exception of the Dodge Caravan, all of the injury criteria for the striking vehicles are below the threshold values. The extremely high Nij value for the 5th percentile passenger in the Dodge Caravan is due to the air bag interaction. For this occupant, the air bag caught the dummy under the chin and produced large neck injury value, indicating a high probability of serious injury or death as a result of the interaction. The agency has initiated a research effort to evaluate more thoroughly the performance of the Chrysler minivan air bag system. The research will involve laboratory studies that will focus on the interaction between the air bag and the crash test dummy. It also will include analysis of findings from the agency's Special Crash Investigations. The agency has not decided what steps, if any, will be taken once the research has been completed. For the Honda Accord, the struck vehicle, only the Caravan and Explorer impacts produced injury criteria that were above the threshold values. These two vehicles were the heaviest striking vehicles. Figure 7 illustrates the effect of the bullet vehicle weight on the normalized injury criteria. There is a general trend of increasing injury criteria with increasing vehicle weight. Notice also that the S-10 and the Explorer are above the best fit line for all of the test cases. This indicates that there maybe some factor other than weight that is influencing the aggressivity of these striking vehicles.

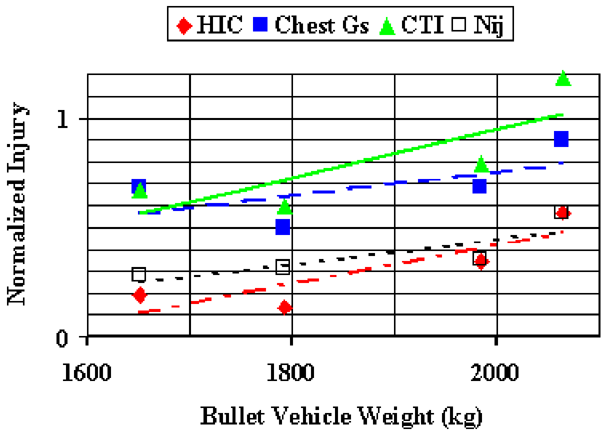

Figure 7 - Injury Measurements for Driver of the target vehicle

Figure 8 shows the comparison between the normalized driver injury and the aggressivity metric as measured by FARS/GES 1991-1994 data. There is a general trend of increasing injury with the increasing aggressivity metric. However, the data from four full scale crash tests are too limited to make broad generalizations.

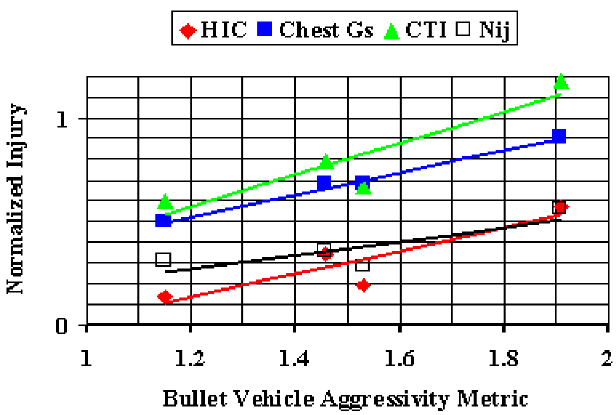

Figure 8 - Injury Measurements for the Driver of the target vehicle

Intrusion measurements were taken for the foot well area of the Honda Accord in the oblique offset test series. The intrusion measurements are shown in Table 8. It is not surprising to note that the lowest intrusions were measured for the Lumina test, and that significantly higher intrusion measurements were recorded for the Explorer and Caravan tests.

FUTURE WORK

To evaluate the aggressivity of a large pickup truck for comparison, the Chevrolet CK2500 will be included in this test series in the near future. Additionally, in order to support finite element simulations of the tests, detailed vehicle measurements will be conducted for the post-test vehicles in this series.

NHTSA is currently evaluating plans to separately evaluate some of the factors involved in vehicle compatibility: mass, geometry and stiffness. Testing supported by computer simulation will be used to develop a better understanding of the influence of vehicle factors upon compatibility.

CONCLUSION

The side impact test series did not show a strong relationship between the injury measures for the driver of the struck vehicle and either the mass of the striking vehicle or the aggressivity metric developed from FARS/GES data. However, the oblique offset test series did show good correlations of driver injury measures with both the vehicle mass and the aggressivity metric. Furthermore, the frontal offset tests indicated that, even accounting for mass differences, there are additional factors that maybe affecting vehicle aggressivity. More research needs to be conducted to better understand how specific vehicle characteristics affect compatibility.

REFERENCES

1. Gabler, H. C. and Hollowell, W. T., "NHTSA's Vehicle Aggressivity and Compatibility Research Program", *Proceedings of the Sixteenth International Enhanced Safety of Vehicle Conference*, Paper No. 98-S3-O-01, Windsor Canada (1998)
2 Gabler, H. C. and Hollowell W. T., "The Aggressivity of Light Trucks and Vans in Traffic Crashes", Society of Automotive Engineers Paper No. 980908, February 1998.
3 Stucki, Sheldon L., Hollowell, William T., and Fessahaie, Osvaldo, "Determination of Frontal Offset Test Conditions Based on Crash Data," Sixteenth International Technical Conference on Enhanced Safety of Vehicles, Windsor, Canada, June, 1998.

Table 4 - Side Impact Bullet Vehicle Responses

Injury Measure	IARV	S-10	Explorer	Caravan	Lumina
Driver - 50th Percentile Male					
HIC	1000	98	82	175	72
Chest Acceleration (g)	60	18.9	13.6	22.1	23.5
Chest Compression (mm)	76	19.5	11.1	23.2	20.5
Combined Thoracic Index -CTI	1.0	0.41	0.27	0.48	0.48
Neck Injury Criteria - Nij	1.4	1.05	0.39	0.96	0.28
Right Femur Compression (N)	10,000	1392	1888	1265	2019
Left Femur Compression (N)	10,000	1636	2454	1583	750
Right Front Passenger - 5th Percentile Female					
HIC	1000	98	148	98	151
Chest Acceleration (g)	60	21.6	13.8	21.5	32.9
Chest Compression (mm)	62	14.8	5.5	17.5	13.0
Combined Thoracic Index -CTI	1.0	0.43	0.23	0.37	0.54
Neck Injury Criteria - Nij	1.4	0.96	0.47	0.96	0.46
Right Femur Compression (N)	6,800	1640	863	1014	1082
Left Femur Compression (N)	6,800	2213	1181	976	1341

Table 5 - Side Impact Target Vehicle Responses (Honda Accord)

Injury Measure	IARV	Bullet Vehicle				
		S-10	Explorer	Caravan	Lumina	MDB
Driver - SID with H3 Neck						
HIC	1000	314	395	193	242	527
TTI (d)	85	88	114	89	91	76
Pelvis Acceleration (g)	130	90	74	128	87	73
Left Rear Passenger - SID with H3 Neck						
HIC	1000	365	307	260	392	765
TTI (d)	85	47	40	39	45	70
Pelvis Acceleration (g)	130	49	38	49	68	77

Table 6 - Oblique Offset Target Vehicle (Honda Accord) Responses

		Bullet Vehicle			
Injury Measure	IARV	S-10	Caravan	Explorer	Lumina
Driver - Hybrid III 50th Percentile Dummy					
Head Injury Criteria - HIC	1000	194	344	567	133
Chest Acceleration (g)	60	40.8	40.7	54.1	29.7
Chest Compression (mm)	76	19	32	55	25
Combined Thoracic Index -CTI	1.0	0.67	0.79	1.18	0.60
Neck Injury Criteria - Nij	1.4	0.39	0.49	0.79	0.44
Right Femur (N)	10000	-	9477	5279	5513
Left Femur (N)	10000	-	3546	13343	2960
Passenger - Hybrid III 5th Percentile Dummy					
Head Injury Criteria - HIC	1000	126	340	322	142
Chest Acceleration (g)	60	42.2	56	49.4	47.6
Chest Compression (mm)	62	2	38	35	31
Combined Thoracic Index -CTI	1.0	0.52	1.11	1.00	0.93
Neck Injury Criteria - Nij	1.4	0.41	0.41	0.66	0.65
Right Femur (N)	6800	886	2558	3173	1561
Left Femur (N)	6800	453	2438	1119	606

Table 7 - Oblique Offset Bullet Vehicle Responses

Injury Measure	IARV	S-10	Caravan	Explorer	Lumina
Driver - Hybrid III 50th Percentile Dummy					
Head Injury Criteria - HIC	1000	363	424	296	351
Chest Acceleration (g)	60	38.2	44.1	33.3	46.8
Chest Compression (mm)	76	39	30	25	38
Combined Thoracic Index -CTI	1.0	0.83	0.81	0.64	0.92
Neck Injury Criteria - Nij	1.4	0.53	0.62	0.51	0.93
Right Femur (N)	10000	-	4889	4757	4312
Left Femur (N)	10000	-	4061	5312	4599
Passenger - Hybrid III 5th Percentile Dummy					
Head Injury Criteria - HIC	1000	78	580	108	559
Chest Acceleration (g)	60	39	48.2	38.5	39.6
Chest Compression (mm)	62	30	30	32	23
Combined Thoracic Index -CTI	1.0	0.82	0.92	0.83	0.74
Neck Injury Criteria - Nij	1.4	0.60	4.4	0.56	1.15
Right Femur (N)	6800	112	2671	2748	1379
Left Femur (N)	6800	409	2530	3086	2807

Table 8 - Intrusion measurements for the Honda Accord in the Oblique Offset Test Series

Striking Vehide	Left Footrest (top)	Left Footrest (bottom)	Brake Pedal Center	Top Left Footwell Firewall	Top Right Footwell Firewall	Bottom Left Footwell Firewall	Bottom Right Footwell Firewall
Caravan	39.6 cm	31.2 cm	31.4 cm	34.9 cm	26.4 cm	26.0 cm	19.0 cm
Lumina	10.2 cm	5.7 cm	1.27 cm	8.6 cm	3.49 cm	5.7 cm	-.63 cm
Explorer	33.6 cm	24.4 cm	34.6 cm	32.3 cm	26.0 cm	24.1 cm	20.3 cm
S-10	11.1 cm	7.3 cm	16.2 cm	13.6 cm	4.1 cm	7.6 cm	1.9 cm