NHTSA's FRONTAL OFFSET RESEARCH PROGRAM

James W. Saunders III
Aloke Prasad
National Highway Traffic Safety Administration
United States
Paper Number 05-0206

ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) is conducting research programs to develop test procedures to reduce death and injury, in particular debilitating lower extremity injuries in frontal offset collisions. This paper presents updated results of Offset Deformable Barrier (ODB) crash tests conducted for the NHTSA. The ODB crash tests were conducted with 50th percentile male and 5th percentile female Hybrid III dummies fitted with advanced lower legs, Thor-Lx/HIIIr and Thor-FLx/HIIIr, to assess the potential for debilitating and costly lower limb injuries. This paper also investigates the implications that the ODB test procedure may have on fleet compatibility by evaluating the results from vehicle-to-vehicle crash tests.

INTRODUCTION

In the United States, driver and right front passenger air bags are required in all passenger cars and light trucks under Federal Motor Vehicle Safety Standard (FMVSS) No. 208, "Occupant crash protection." However, NHTSA estimates that over 8,000 fatalities and 120,000 Abbreviated Injury Scale (AIS) 2+ injuries will continue to occur in frontal crashes even after all passenger cars and light trucks have frontal air bags. Therefore, NHTSA has focused on the development of performance tests not currently addressed by FMVSS No. 208, particularly high severity frontal offset crashes. These tests are planned to result in high decelerations to evaluate restraints and large occupant compartment intrusion that could compromise occupant survival space and thus increase the potential for lower leg injury.

Since the European Union directive 96/79 for frontal crash protection became effective in 1998, other countries and consumer rating programs have adopted the use of a fixed ODB crash test procedure. The Australian and European regulations require the ODB crash test at 56 km/h while the consumer rating programs, Euro NCAP (European New Car Assessment Program), Australian NCAP and IIHS (Insurance Institute for Highway Safety) conduct the ODB crash test at 64 km/h.

Research into the design of an improved ODB test procedure for the U.S. needs to evaluate the various test speeds to determine the best options. Saunders, et. al, [1] showed that a high speed ODB test procedure (combining 56, 60, or 64 km/h tests) appeared to correctly predict the risk and proportion of below-the-knee injuries in severe real world offset crashes, but under estimated the risk of thoracic and knee-thigh-hip injuries. Saunders also reported on three pairs of vehicle-to-vehicle crash tests in which the redesigned vehicle in each pair obtained a better rating in the IIHS ODB tests than its respective older model (the other vehicle in the pair). The redesigned vehicle models were found to be more aggressive in these crash tests than their older counterparts as demonstrated by the injury measures of the dummies in the target vehicle. However, Saunders could not establish a relationship between the increase in aggressivity of the redesigned vehicles and the corresponding increase in front end stiffness in the redesigned vehicle due to the confounding effects of vehicle mass and vehicle front end geometry of the redesigned vehicle. This paper begins with presentation and discussion of data to more fully examine the effect of speed and dummy size on a rigid barrier ODB crash test. The next part of the paper investigates the effect that the high speed rigid offset deformable barrier test procedure may have had on the fleet compatibility.

RIGID OFFSET DEFORMABLE BARRIER CRASH TESTS

This section summarizes results from ODB test series run for NHTSA that were conducted using the procedure defined in FMVSS No. 208, Occupant Crash Protection (S18). In all tests the driver and front seat passenger were two Hybrid III 50th percentile males (HIII 50M) with the Thor-Lx/HIII retrofit lower leg, or two Hybrid III 5th percentile females (HIII 5F) with the Thor-FLx/HIII retrofit lower leg. The HIII 50M and HIII 5F dummy positioning was done in accordance with FMVSS No. 208. The purpose of these tests was to study the effect of speed and dummy.

Injury Assessment Reference Values

The Injury Assessment Reference Values (IARV) for the HIII 50M and HIII 5F dummies that were developed for the FMVSS No. 208 Advanced Air Bag Final Rule were used. The IARV for the lower leg was conducted according to Kuppa et al., [2, 3]. The IARVs used to assess injuries below the knee are presented in Table 1.

Table 1

IARVs for injuries below the knee

Injury Criteria	IARV for HIII 50M	IARV for HIII 5F
knee shear	15 mm	13 mm
Upper tibia axial force	5600 N	4000 N
Lower tibia axial force	5200 N	3750 N
Upper tibia index *	F/12000+M/240<0.91	F/8640+M/146<0.91
Lower tibia index *	F/12000+M/240<0.91	F/8640+M/146<0.91
Dorsiflexion	35 deg	35 deg
Inversion/eversion	35 deg	35 deg

* F= axial force in N, M is resultant moment in Nm.

ODB Crash Tests Results

Table 2 shows the percentage of tests that exceed the IARVs for the HIII 50M and HIII 5F at both 56 kmph and 60 kmph. The general trend is that the 56 kmph tests had lower proportions of below the knee injuries as compared to the 60 kmph tests.

Table 2

ODB Crash Tests

	56 kmph		60 kmph	
	5th	50th	5th	50th
Number of tests	6	5	7	5
	Percentage That Exceeded IARV			
Chest g's	0.0	0.0	0.0	0.0
Chest Displacement	0.0	0.0	0.0	0.0
HIC 15	16.7[1]	40.0[2]	0.0	0.0
Nij ver. 10	16.7[1]	0.0	57.1	0.0
Neck Tension	16.7[1]	0.0	0.0	0.0
Neck Compression	0.0	0.0	0.0	0.0
Femur Load	0.0	0.0	0.0	0.0
Knee Shear	0.0	0.0	0.0	0.0
Upper Tibia Index	16.7	0.0	0.0	40.0
Lower Tibia Index	16.7	20.0	42.9	40.0
Upper Tibia Axial Force	0.0	0	0.0	20.0
Lower Tibia Axial Force	16.7	20.0	28.6	40.0
Dorsiflexion	16.7	40.0	57.1	60.0
Inversion/Eversion	0.0	0.0	14.3	0.0

[1] Due to delayed deployment of the air bag
[2] Due to the air bag did not deploy during the test

Comparison of 50th and 5th lower leg Injury Assessment Values (IAVs)

This section compares paired ODB crash tests of the same vehicle model and closing speed with both a HIII 50M and HIII 5F in the driver's position. Figures 1 and 2 show that in four out of the five paired vehicle tests the HIII 50M had a higher percent IARV for the femur load and knee shear, respectively, than the HIII 5F. The percent of IARV for upper and lower tibia index for the HIII 5F was higher for all paired vehicles tested compared to the HIII 50M, except the upper tibia index of the Quest. The HIII 50M upper tibia index was 2.23, whereas the HIII 5F was only 0.79 (Figures 3 and 4). The percent of IARV for the upper and lower tibia axial force was higher in four out of the five paired tests for the HIII 5F when compared to the HIII 50M (Figures 5 and 6). In four out of the five paired tests the percent IARV for dorsiflexion angle of the HIII 5F was higher than the HIII 50M (Figure 7). The inversion/eversion angle was higher for the HIII 50M compared to the HIII 5F in all the paired tests (Figure 8).

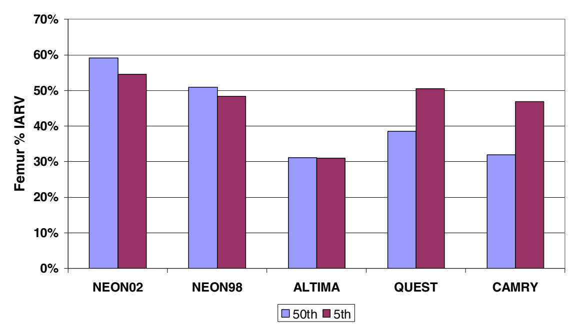

Figure 1. Comparison of femur percent IARV.

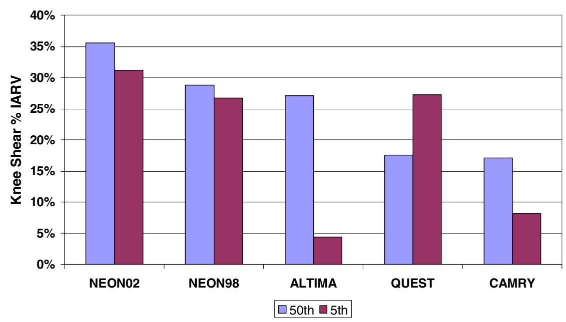

Figure 2. Comparison of knee shear percent IARV.

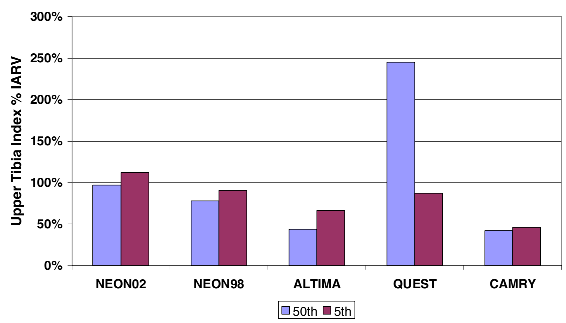

Figure 3. Comparison of upper tibia index percent IARV.

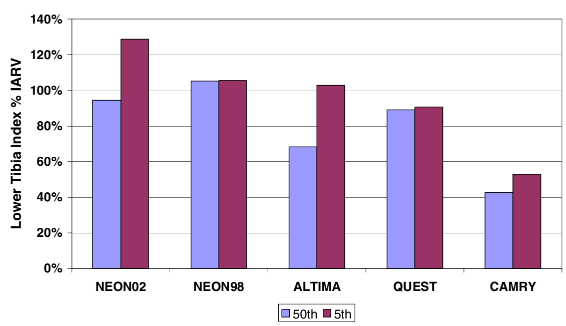

Figure 4. Comparison of lower tibia index percent IARV.

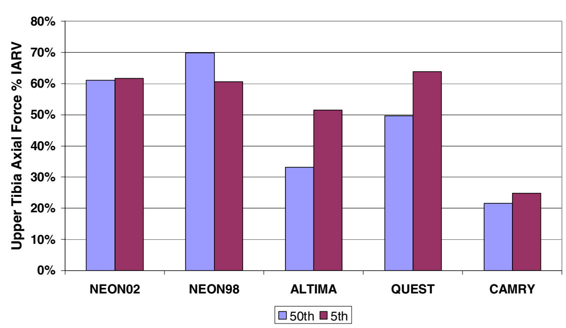

Figure 5. Comparison of upper tibia axial force percent IARV.

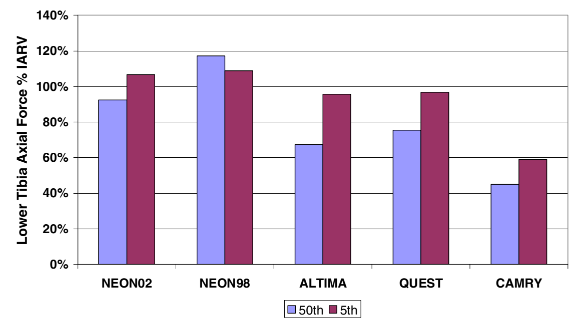

Figure 6. Comparison of lower tibia axial force.

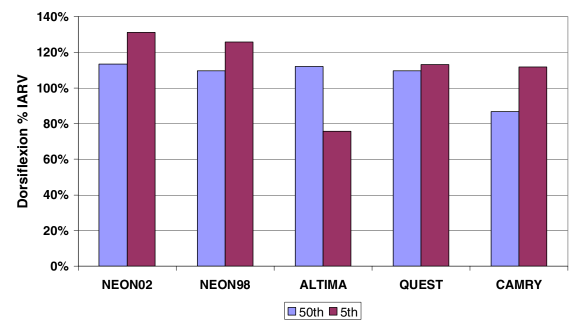

Figure 7. Comparison of dorsiflexion percent IARV.

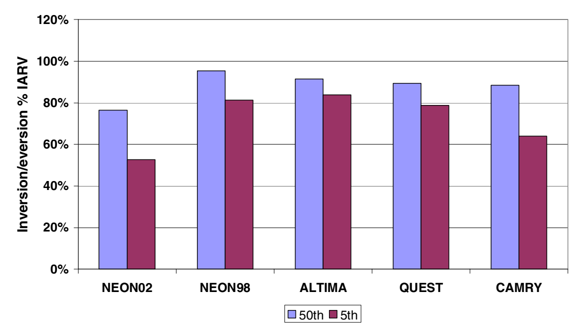

Figure 8. Comparison of inversion/eversion percent IARV.

VEHICLE-TO-VEHICLE CRASH TESTS

Vehicle Test Matrix

In order to build an improved understanding of the before-and-after fleet response to offset fixed barrier testing and redesign, an additional three pairs of vehicles were added to the three pairs of vehicle-to-vehicle tests reported in Saunders, et. al, [1]. The paired vehicles added to the test matrix were two mid-size vehicles (Avalon and Seville) and a van (Sienna,), thus creating the test matrix of Table 3. The paired bullet vehicles were to be crashed into a moving 1996 Honda Accord target, as was done in previous testing. The approach was to select the same vehicle make and model with one being an older model and rated "poor" or "marginal" in the

IIHS ODB test while the other was a newer redesigned model and rated “marginal” or “good” in the IIHS ODB test. The frontal oblique vehicle-to-vehicle crash test series was conducted using a test procedure developed under NHTSA’s Advanced Frontal Offset Research Program (Stucki, et al., [4]).

Table 3

Striking vehicle-to-Accord test matrix

Original	**After Re-design**
1997 Chevrolet Blazer IIHS Rating = Poor Test weight = 2130 kg (4686 lb) NHTSA Test # = 4363	**2002 Chevrolet TrailBlazer** IIHS Rating = Marginal Test weight = 2355 kg (5181 lb) NHTSA Test # = 4364
1999 Mitsubishi Montero Sport IIHS Rating = Poor Test weight = 2112 kg (4646 lb) NHTSA Test # = 4474	**2001 Mitsubishi Montero Sport** IIHS Rating = Good Test weight = 2143 kg (4715 lb) NHTSA Test # = 4438
2001 Dodge Ram 1500 IIHS Rating = Poor Test weight = 2531 kg (5568 lb) NHTSA Test # = 4581	**2002 Dodge Ram 1500** IIHS Rating = Good Test weight = 2572 kg (5658 lb) NHTSA Test # = 4617
1996 Toyota Avalon IIHS Rating = Marginal Test weight = 1702 kg (3744 lb) NHTSA Test # = 4660	**2000 Avalon** IIHS Rating = Good Test weight = 1728 kg (3802 lb) NHTSA Test # = 4667
1997 Cadillac Seville IIHS Rating = Poor Test weight = 2012 kg (4426 lb) NHTSA Test # = 4937	**2000 Cadillac Seville** IIHS Rating = Good Test weight = 2007 kg (4415 lb) NHTSA Test # = 4955
1996 Toyota Previa IIHS Rating = Poor Test weight = 1953 kg (4297 lb) NHTSA Test # = 4924	**1998 Toyota Sienna** IIHS Rating = Good Test weight = 2024 kg (4453 lb) NHTSA Test # = 4925

To better understand the agressivity characteristics of the vehicles in the test matrix, we decided to evaluate their initial crash stiffness. NHTSA’s New Car Assessment Program (NCAP) measures the total force applied to the rigid wall in a full frontal rigid barrier crash test. Figures 9 through 11 show the force-deflection profiles obtained from the NCAP tests of the original and redesigned RAM 1500, Blazer/TrailBlazer and the Avalon. Similar force-deflection profiles are not available for the other paired vehicles. The general trend of the force-deflection profiles is that the redesigned RAM 1500 and Trailblazer have a higher onset rate of force. They also have a peak force that is higher and occurs earlier in the event as compared to the original vehicles. In addition, the deflection of the redesigned RAM 1500 and Trailblazer was lower than the corresponding original vehicles. The redesigned and original Avalon had similar force-deflection profiles.

The initial stiffness of the vehicles was computed according to the method outlined by Swanson, et al., [5] and presented in Table 4. The initial stiffness is higher for the redesigned vehicles than for the original vehicles, except for the Avalon, which decreased slightly according to the method.

Table 4

Initial Stiffness of the Ram 1500, the Trailblazer and the Avalon.

Vehicle Model	Pre-redesigned	Redesigned
Ram 1500	1985 N/mm	2732 N/mm
Blazer/Trailblazer	1528 N/mm	2479 N/mm
Avalon	1334 N/mm	1266 N/mm

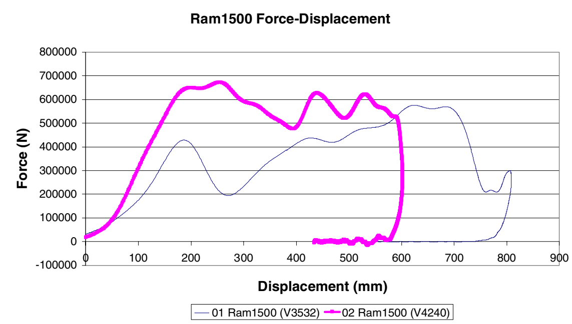

Figure 9. RAM 1500 Force deflection profile from NCAP test.

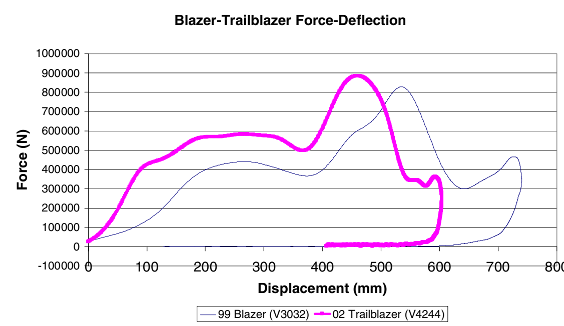

Figure 10. Blazer/Trailblazer Force deflection profile from NCAP test.

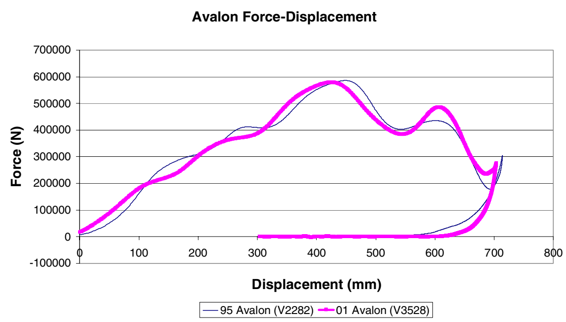

Figure 11. Avalon Force deflection profile from NCAP test.

Oblique Frontal Vehicle-to-Vehicle Crash Tests

In order to better understand the real world effects of redesigning a vehicle to meet the rigid offset deformable barrier tests, the vehicle test matrix was implemented in oblique frontal crash testing. The tests were conducted in the configuration of Figure 12.

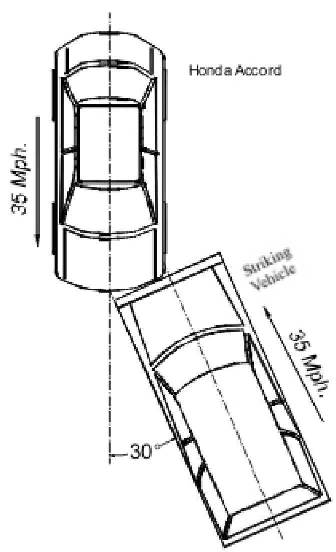

Figure 12. Oblique Offset Test Configuration.

Figures 13 through 16 present the injury measures for the HIII 50M driver of the Accord, along with the IARVs specified in the FMVSS No. 208 Advanced Air Bag Final Rule.

The HIC IARV for the driver of the Accord was exceeded in both the original and redesigned Trailblazer and the redesigned Montero (Figure 13). Four of the redesigned vehicles had higher HIC values, for the driver of the Accord, than the original vehicles. The high HIC for the driver in the Accord in the crash test with the redesigned 2002 TrailBlazer was due to head contact with the hood of the TrailBlazer. There was also head contact for the driver in the Accord with the hood of the corresponding older model (Blazer), but it was not as severe.

The Chest g's IARV were exceeded for the driver of the Accord in the redesigned Blazer, Montero and RAM 1500 (Figure 14). Four out of the six redesigned vehicles had higher Chest g's than the original vehicles for the driver of the Accord. At least one of the IARVs for the driver in the Accord were higher in the crash test with the redesigned vehicle than in the crash test with the corresponding older model. It should be noted that the original RAM 1500 overrode the Accord and eventually rolled over in the test. Though the rollover event occurred after the occurrence of peak injury measures, the overriding of the Accord by the original RAM 1500 may have occurred earlier.

Only the redesigned Trailblazer exceeded the IARV for chest displacement of the driver of the Accord (Figure 15). Three of the six redesigned vehicles had an increase in chest displacement for the driver of the Accord.

The redesigned Trailblazer and Montero and the original Blazer and Previa exceeded the IARV for the femur for the driver of the Accord (Figure 16). Five out of the six redesigned vehicles had a higher femur loads for the driver of the Accord.

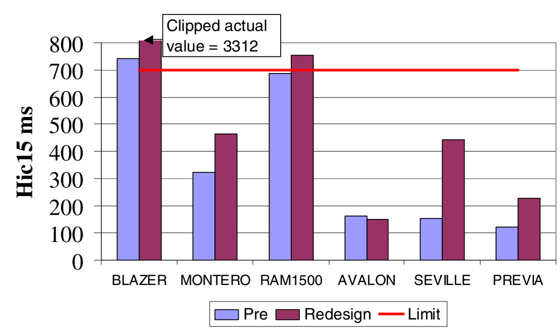

Figure 13. HIC 15 for the HIII 50M driver in the Accord.

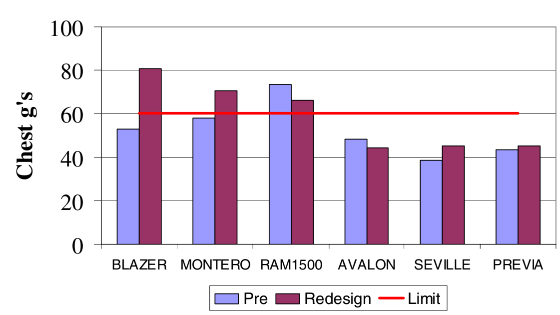

Figure 14. Chest Gs for the HIII 50M driver in the Accord.

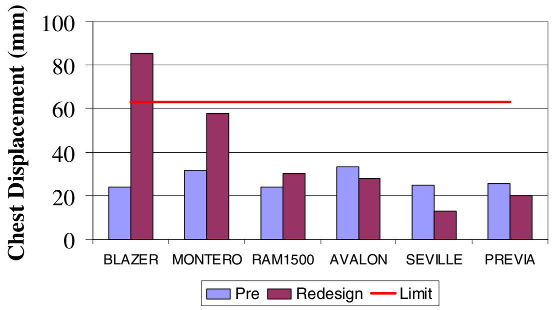

Figure 15. Chest displacement the HIII 50M driver in the Accord.

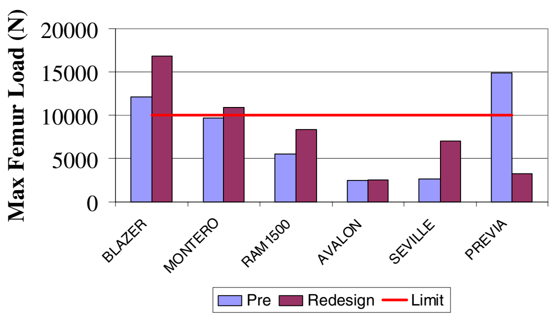

Figure 16. Maximum femur load for the HIII 50M driver in the Accord.

DISCUSSION

Rigid Offset Deformable Barrier Tests

In 2004, Saunders, et. al, [1] combined the ODB test results at 56 kmph, 60 kmph and 64 kmph and predicted the proportion of below the knee injuries when compared to real world data. However, in the present work, when the ODB tests are separated by test speed, we found that the 56 kmph tests do not predict the same proportion of below-the-knee injuries as the tests at 60 kmph, for this sample of vehicles tested, thus showing an important effect of test speed. This outcome needs to be further developed with additional testing.

Oblique Vehicle-to-Vehicle Crash Tests

The paired, redesigned vehicle-to-Accord crash test series generally showed an increased potential for head, chest, and femur injuries in the driver of the Accord as compared to the corresponding older models. This suggests that the redesigned vehicles were more aggressive than their corresponding older models. The redesigned vehicles generally showed an increase in all the injury values, compared to the original vehicles (Figures 13 through 16). However, only the redesigned SUVs and Pickup tested exceeded at least one of the FMVSS No. 208 IARVs for the driver of the Accord. As reported in Saunders, et al., [1] among the paired vehicle-to-vehicle crash tests, only the RAM 1500 demonstrated the most direct association of increased front-end stiffness of the redesigned vehicle to its increased aggressivity. For the other vehicles tested, the effect of stiffness on aggressivity was confounded by geometry and/or vehicle mass.

CONCLUSIONS

The ODB test procedure at 56 kmph predicts a lower proportion of below-the-knee injuries than the 60 kmph, for this set of vehicles tested. Also, there was no general trend in IAVs when comparing the lower leg IAVs of the HIII 50M and the HIII 5F driver. These data suggest that further testing is needed to clarify the effects of speed and dummy size on the results. These tests are currently being designed for implementation this calendar year.

In addition, the redesigned vehicles used in this study that obtained a better rating in the IIHS ODB tests than their respective older models were found to be more aggressive in vehicle-to-vehicle crash tests than their older counterparts. The front-end initial stiffness of the redesigned SUVs and pickup was considerably higher than that of their corresponding older models. However, the initial stiffness of the redesigned Toyota Avalon was not that different from the older counterpart. Though the injury measures on the dummies in the target vehicle were generally higher in oblique crash tests with the redesigned passenger cars than the older counterparts, none of them exceeded their prescribed limits. However, the crash tests with the larger vehicles (SUVs and pickups) resulted in at least one injury measure of the driver in the target vehicle exceeding its prescribed limit. We are exploring this finding in our current program.

REFERENCES

[1] Saunders, J., Kuppa, S., Prasad, A., "NHTSA's Frontal Offset Research Program," Paper 2004-01-1169, Society of Automotive Engineers, March 2004.

[2] Kuppa, S., Wang, J., Haffner, M., Eppinger, R., "Lower Extremity Injuries and Associated Injury Criteria," 17th International Technical Conference on the Enhanced Safety of Vehicles, Amsterdam, The Netherlands, June 4-7, 2001.

[3] Kuppa, S., Haffner, M., Eppinger, R., Saunders, J., "Lower Extremity Response and Trauma Assessment using the Thor-Lx/HIIIr and the Denton leg in Frontal Offset Vehicle Crashes," 17th International Technical Conference on the

Enhanced Safety of Vehicles, Amsterdam, The Netherlands, June 4-7, 2001.

[4] Stucki, Sheldon L., Hollowell, William T., and Fessahaie, Osvaldo, "Determination of Frontal Test Conditions Based on Crash Data," Sixteenth International Technical Conference on Enhanced Safety of Vehicles, Windsor, Canada, June, 1998.

[5] Swanson, J., Rockwell, T., Beuse, N., Summers, L., Summers, S., Park, B., "Evaluation fo Stiffness Measures from the U.S. New Car Assessment Program," 18th International Technical Conference on the Enhanced Safety of Vehicles, Nagoya, Japan, May 19-22, 2003.

Table A 1

IAVs for the HIII 50M

			Closing Speed (kmph)	Test #	Chest G	Chest Disp (mm)	HIC 15	Nij ver. 10	Neck Ten	Neck Comp	Max Femur	Max Knee Shear	Max Up TI	Max Low TI	Max Upper Tibia Axial Force	Max Lower Tibia Axial Force	Max Dorsi-flexion Angle	Max Inversion / Eversion Angle
				IARV	60	63	700	1	4170	4000	9040	15	0.91	0.91	5600	5200	35	35
NISSAN	QUEST	2002	56.0	4439	27.6	26.2	148.8	0.21	602	134	2894	3.27	0.51	1.11	3242	5555	42.2	20.5
LINCOLN	NAVIGATOR*	2003	56.0	4441	31.7	20.1	731.5	0.35	1758	234	3608	2.62	0.25	0.44	931	2192	27.4	16.2
DODGE	NEON	2002	56.1	4428	40.0	26.5	610.5	0.40	1499	51	5351	5.33	0.88	0.86	3418	4803	39.7	26.8
CHEVROLET	TRAILBLAZER*	2003	56.7	4873	41.0	31.1	731.1	0.74	2040	565	6112	0.37	0.35	0.54	1842	3265	33.2	ND
CADILLAC	SEVILLE	2003	56.5	4874	25.1	23.8	46.9	0.61	804	187	1524	0.96	0.43	0.42	1666	2596	24.9	29.0
TOYOTA	CAMRY	1996	60.7	3459	30.7	24.5	245.6	ND	944	693	2893	2.56	0.38	0.39	1206	2344	30.4	31.0
DODGE	NEON	1998	60.8	3466	38.6	28.9	271.4	ND	1708	442	4611	4.32	0.71	0.96	3916	6099	38.4	33.4
NISSAN	QUEST	2000	59.5	3857	28.1	23.3	304.8	0.31	1724	207	3491	2.64	2.23	0.81	2778	3920	38.4	31.3
CHEVROLET	TAHOE	2000	60.4	3855	46.5	21.2	180.5	0.29	1565	171	6304	7.50	1.13	0.94	7649	9404	28.4	26.6
NISSAN	ALTIMA	2002	60.2	4461	36.1	24.6	132.6	0.24	705	402	2810	4.06	0.40	0.62	1857	3506	39.2	32.0

* Air bag did not deploy during tests

Table A 2

IAVs for the HIII 5F

			Closing Speed (kmph)	Test #	Chest G	Chest Disp (mm)	HIC 15	Nij ver. 10	Neck Ten	Neck Comp	Max Femur	Max Knee Shear	Max Up TI	Max Low TI	Max Upper Tibia Axial Force	Max Lower Tibia Axial Force	Max Dorsi-flexion Angle	Max Inversion / Eversion Angle
				IARV	60	52	700	1	2620	2520	6510	13	0.91	0.91	4000	3750	35	35
DODGE	NEON	2002	56.0	4377	44.133	35.294	1202	1.511	3533	183.4	3550.08	4.06	1.022	1.172	2468.72	4005.33	45.96	18.47
NISSAN	ALTIMA	2002	56.1	4431	37.094	22.001	39.35	0.583	1009	307.7	1911.57	0.545	0.292	0.385	1230.63	1986.04	30.45	17.81
DODGE	RAM1500*	2003	56.5	4869	28.884	23.412	160.3	0.295	772.8	398.9	1792.06	4.036	0.594	0.242	572.13	692.32	3.32	15.36
TOYOTA	AVALON	2003	56.7	4870	30.901	23.22	116.7	0.629	1219	177.1	2228.51	1.569	0.386	0.415	750.8	1007.59	4.63	ND
MITSUBISHI	MONTERO SPORT	2003	56.3	4875	48.393	24.842	61.96	0.783	1267	108.8	2062.15	5.212	0.589	0.618	2380.39	2954.75	21.04	ND
TOYOTA	SIENNA	2003	56.0	4669	28.476	25.355	303.6	0.787	1919	49.03	1556.82	0.897	0.523	0.523	566.63	715.42	3.06	10.35
TOYOTA	CAMRY	1996	59.9	3664	31.778	32.894	141.7	1.24	1601	158.8	3050.82	1.068	0.42	0.48	995.39	2213.49	39.12	22.43
SUBARU	LEGACY	2000	59.9	3665	36.385	26.192	146	1.068	1702	77.45	2935.58	1.55	0.38	0.58	1545.85	3006.35	34.74	34.74
NISSAN	ALTIMA	2000	60.0	3666	33.541	22.567	110.9	1.28	1630	349.7	4582.93	3.776	0.82	1.55	2930.04	5519.34	41.71	37.11
DODGE	NEON	1998	60.4	3667	45.399	28.071	611	0.557	2081	842.9	3152.16	3.476	0.825	0.96	2425.64	4086.57	44	28.45
NISSAN	QUEST	2000	60.0	3856	28.774	15.552	96.72	0.49	1081	119.6	3291.03	3.541	0.792	0.826	2555.15	3628.3	39.65	27.56
FORD	EXPLORER	2000	59.85	3850	31.788	30.956	111.3	1.317	1742	444.9	3700.77	0.559	0.383	0.423	1519.39	1908.33	22.4	18.72
NISSAN	ALTIMA	2002	59.8	4440	32.226	26.578	76.83	0.429	907.9	337.3	2019.3	0.576	0.605	0.936	2058.94	3585.99	26.55	29.33

* Air bag did not deploy during test