OFFSET TEST DESIGN AND PRELIMINARY RESULTS

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ABSTRACT

The National Highway Traffic Safety Administration (NHTSA) is conducting a research program to investigate the feasibility of a high speed frontal offset deformable barrier (ODB) crash test to improve frontal occupant crash protection. The focus of the program is to reduce debilitating lower extremity injuries in frontal offset collisions. This paper discusses three areas of research in this program: new seating procedure, preliminary results of the new crash test, and an analysis of frontal stiffness characteristics of redesigned vehicles and their ODB test procedure performance.

The new seating procedure uses Hybrid III male dummies fitted with Thor-LX/HIII legs (HIII50LX). A particularly challenging problem was the development of a test procedure with repeatable positioning of the Thor-LX/HIII feet with respect to the pedals in some vehicles. inversion/eversion was the primary failure mode of the ankle was. The kinematics and mechanism of this failure are examined.

Preliminary data are presented that compare the frontal stiffness characteristics of vehicle models that were redesigned and used in both NCAP and IIHS crashworthiness rating programs. The potential impact of this on the compatibility of the light vehicle fleet is discussed.

INTRODUCTION

In vehicle crashes lower limb injuries are the second most common site of AIS 2+ injuries (Thomas, 1995). These lower leg injuries also have been reported to be the cause of permanent disability and Impairment (Burgess et al., 1995). Kuppa et al., 2001a, showed that the foot and ankle AIS 2+ injuries are 33% of lower leg injuries and 41% of associated Functional Life-years Lost to injury.

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 large occupant compartment intrusion that could compromise occupant survival space and thus increase the potential for lower leg injuries. The ODB test procedure is being evaluated for its potential to predict lower leg injuries.

Saunders et al., 2004 showed that a high speed ODB test procedure (combining 56, 60, and 64 km/h test) appeared to correctly predict the risk and proportion of below-the-knee injuries in severe real world offset crashes, especially the proportion of foot and ankle injuries. In these tests Saunders used the Thor-Lx/HIII retrofit advanced lower leg. The Thor-Lx has rotational potentiometers to measure dorsiflextion, inversion/eversion, and internal/external rotations of the foot. This gives the Thor-Lx the ability to predict ankle and foot injuries. The current lower leg of the HIII does not have the ability to predict these foot and ankle injuries.

University of Michigan Transportation Research Institute (UMTRI) has conducted studies documenting the seating positions used by various sized humans. They have developed a mathematical regression for locating the seat longitudinal position based on those studies. The Insurance Institute for Highway Safety (IIHS) has adopted this procedure in their ODB test and had petitioned the agency to do so as well.

NHTSA has been using dummy seating procedures based on seat mid-track position for frontal crash tests with the HIII 50th percentile male. UMTRI found that the average person does not position the seat at mid-track in its study. Therefore, NHTSA has been investigating different seating procedures that do not use the seat track position. NHTSA has investigated the IIHS seating procedure and found that this procedure may not always put the right foot in the neutral position on the accelerator pedal because the procedure was developed using regression analysis with scatter in the data.

The current effort has developed a dummy seating position built on a different paradigm. This seating procedure uses a step-by-step process that mimics the procedures used by humans, thus avoiding the errors introduced by regression and by evolving vehicle interior designs. The procedures are described in

sections below and listed in Appendix A.

Since the EU 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 regulation requires an ODB crash test at 56 km/h while their consumer rating programs, Euro NCAP (European New Car Assessment Program), Australian NCAP, and IIHS conduct the ODB crash test at 64 km/h. IIHS has evaluated over 150 vehicle models using their 64 km/h ODB crash test procedure and indicated in a status report (September, 2001) that various vehicle models that had received a "poor" rating were redesigned and later obtained "good" or "marginal" rating in their ODB crash tests. According to IIHS, this improved performance in the redesigned vehicles was attributed to vehicle structure design that prevents major collapse of the occupant compartment. Nolan and Lund (2001) found that the majority of vehicles (mainly passenger cars) whose structural performance improved in the IIHS frontal offset crash tests after being redesigned did so without significant alteration to the stiffness of the vehicle for the first half-meter of deformation. However, General Motors Corporation (Verma, et al., 2003) indicated that the use of fixed barriers as a test device may lead to higher force levels for front ends of larger vehicles and could act to increase the incompatibility between large and small vehicles. Saunders (2005) reported on 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 the redesigned vehicle's mass and vehicle front end geometry.

This paper presents the preliminary results of NHTSA's research on a high speed (56 km/h) ODB test. First, a description is provided of the dummy-based seating procedure and the repeatability of this procedure is presented. This is followed by a discussion of the results of the ODB tests using this new seating procedure. Next, the Thor-Lx/HIII kinematics is analyzed from the rotational data recorded and a description of the mechanism that caused the ankle to rotate. And finally, the paper discusses the potential concerns of an ODB test procedure on the compatibility of the light vehicle fleet.

SEATING PROCEDURE

This section describes a seating procedure that mimics the procedures used by humans to position themselves in the vehicle. This procedure ensures the feet are in neutral position and the right foot is placed on the accelerator pedal, which provides proper dummy interaction with the vehicle interior to be able to predict lower leg injuries.

DESCRIPTION OF DUMMY-BASED SEATING PROCEDURE FOR HIII50LX DUMMY:

Driver:

A seating procedure was developed for the HIII50LX in the driver seat based on the assumption that the longitudinal position of the seat is determined by the proper placement of the right foot on the accelerator pedal. The seat was moved to the full-rear position and was placed in the full down position with the seat cushion at its mid angle position. The H-point tool (OSCAR) was used to get a predefined H-point location. The OSCAR was used to find a repeatable and consistent starting position for the dummy. The feet of the dummy were placed in neutral position (X and Z rotation of zero degrees and Y rotation of -15 degrees), which is the most stable position of the feet for the Thor Lx legs.

The seat was then moved forward to place the right foot on the accelerator pedal such that:

1. The foot was in neutral position.
2. The heel was resting on the floor pan (with carpeting but without floor mats). The floor mats were removed to avoid inconsistency caused by various after-market mats that might be provided as dealer options.
3. The heel was at the same lateral location as the accelerator pedal, as defined by the heel-point (intersection of the pedal line of symmetry and the floor pan).
4. The accelerator pedal was not depressed.
5. The thigh-leg-foot was in the same vertical plane.

Procedures were developed for two configurations of vehicle interior:

1. Vehicle with brake and clutch pedals either removed or permanently depressed
2. Vehicle with brake and clutch pedals in un-depressed position

In most instances, the brake/clutch pedals are rearward (closer to the seat) than the accelerator pedal. Thus, if the brake/clutch pedals are left in their un-depressed state, the left foot was unable to be positioned at the same longitudinal and symmetric position as the right foot. The left foot was then placed on the un-depressed brake/clutch pedal and the left knee was at an elevated position compared to the right knee.

In order to place the left foot laterally symmetric to the right foot and at the same longitudinal position as the right foot, the pedals were depressed artificially and held in that position by mechanical means. This was considered to be an alternative way of placing the left foot.

All repeatability data is based on the above procedure.

Subsequent discussions on avoiding the placement of the left foot on the brake or clutch pedals resulted in a variation of the seating procedure. This procedure moves the left foot to the left to avoid lateral overlap with the pedals before the seat is moved forward. This procedure is listed in Appendix A and was selected for use in these offset crash tests. The procedure in Appendix A is assumed to provide the same repeatability as the procedure with the pedals depressed artificially and held in that position by mechanical means.

Passenger:

The intent for the final position on the passenger side was to have the feet in the neutral position and as far forward as possible, preferably on the toe-pan. The initial seat position and dummy placement were the same as the driver. The feet were placed together to avoid early contact with the wheel-well and center tunnel projections. The toes were pushed down towards the floor (in extension, away from the neutral position) to avoid contact with ducts in the lower dashboard, and the seat was moved forward until the feet contacted the vehicle interior or the seat reached the full-forward position. The feet were then returned to neutral position and separated symmetrically to get the knee separation of 10.8 inches (like in the current FMVSS No. 208 procedure) or until contact was made with the vehicle interior.

TEST PROCEDURE DEVELOPMENT

Five vehicles were selected for use in developing this test procedure. These vehicles range in size from small passenger car to LTV.

The vehicles used were:

1. 2002 Ford Focus
2. 2005 Cadillac STS
3. 2005 VW Jetta
4. 2005 Honda Ridgeline
5. 2005 Honda Odyssey

Two teams of technicians were used to study the repeatability and reproducibility of the seating procedure. Each team repeated the seating procedure three times. An initial determination of the OSCAR H-point and pelvic angles (with the seat full rear and full down) was made once and used in all seating tests. A coordinate measuring tool (FARO) was used throughout to measure the seat position and the dummy's head, pelvis, knee, and ankle location.

DISCUSSION OF SEATING PROCEDURE TESTS:

The dummy-based procedure consistently placed the driver seat to the rear of the mid-track location used in FMVSS No. 208. Figures 1 shows the positions for the Ford Focus using the current mid-track seating procedure and using the dummy-based seating procedure. The dummy-based procedure placed the seat 3.1 inches rear of the mid-track position for the Focus.

For the passenger side, the forward progress of the dummy in the dummy-based procedure was determined by the layout of the lower dash and ducts. The positions for the Cadillac (which had the greatest difference from the mid-track position) using the current mid-track procedure and using the dummy-based seating procedure are shown in Figure 2.

Figure 1 Ford Focus Driver – (a) Mid-track Position, (b) Dummy-based Position.

Figure 2 Cadillac STS Passenger – (a) Mid-track Position, (b) Dummy-based Position

REPEATABILITY, REPRODUCIBILITY, AND COMPARISON OF THE PROCEDURES

Each team (Team 1 or Team 2) repeated the dummy-based procedure 3 times for each vehicle for the driver and for the passenger sides. Also, each team repeated the current FMVSS No. 208 procedure twice, except for Jetta.

Figure 3 and Figure 4 show the location of the driver's ankle, knee, H-Point, and head CG in the longitudinal-vertical plane (such as when looking at the dummy through the open doorway) for each of the vehicles for the dummy based and mid-track procedure, respectively. The results show that the repeat measurements taken by each team are within +/- 1 inch for the dummy based and mid-track procedure, respectively. The results also show that the average measurement between each team was within +/- 1 inch for both procedures. This demonstrates that the dummy based seating procedure is as repeatable and reproducible as the mid-track procedure. The results for the passenger were similar to the driver.

TEST RESULTS

This section summarizes results from the ODB crash test series run for NHTSA that was conducted using the procedure defined in FMVSS No. 208 (S18) with a modification to the seating procedure. In all tests, the HIII50LX was positioned according to the seating procedure presented above. The HIII50LX was instrumented to calculate the Injury Assessment Values (IAVs) as defined in the FMVSS No. 208 Advanced Air Bag Final Rule. The following is a list of FMVSS No. 208 IAVs used in this test series:

1. Head injury criteria with a time interval of 15 ms (HIC15).
2. IAVs for the neck includeing Nij, neck tension (N), and neck compression (N).
3. Chest acceleration whose cumulative acceleration is not more than 3 ms (Clip3ms).
4. Chest compression (mm).
5. Femur load (N).

The Thor-Lx/HIII was instrumented with upper and lower tibia load cells, three ankle rotational potentiometers, and tri-axial foot accelerometers. The polarities of the data channels were recorded according to SAE J211. The IAVs calculated for the Thor-Lx/HIII include the following:

1. Upper and lower tibia compressive force (N).
2. Upper and lower tibia index (TI) is calculated using the following equation:

$$TI=F/12000+M/240 \qquad (1)$$

Where: F=axial Force in N
M=the resultant moment (Nm) of the x and y tibia moments

3. Knee shear (mm)
4. Ankle rotation
   a. Dorsiflextion (degrees) is the maximum positive y rotation.
   b. Inversion/eversion (degrees) is the maximum of either the positive or negative x rotation.

The injury assessment reference values (IARVs) used to determine the probability of injury are listed in Table 1 (Kuppa, et. al. 2001a and 2001b).

Table 1
IARVs

Injury Criteria	IARV for HIII 50M
HIC15	700
Nij	1.0
Neck tension	4170 N
Neck compression	4000 N
Clip3ms	60
Chest compression	63 mm
Femur load	10008 N
knee shear	15 mm
Upper tibia axial force	5600 N
Lower tibia axial force	5200 N
Upper tibia index	0.91
Lower tibia index	0.91
Dorsiflexion	35 deg
Inversion/eversion	35 deg

ODB CRASH TESTS RESULTS

The crash tests showed that 1 of the 6 vehicles tested had all the IAVs below the IARVs (Table 2 and 3). The only time the HIC15 exceeded its IARV was when the dummy rebounded from the air bag and the dummy's head hit the b-pillar. All vehicles that exceeded at least one of the IARVs also exceeded the inversion/eversion IARV for either the left and/or right foot. The only vehicle that exceeded the TI IARV was the Dodge Stratus. Next, the kinematics of the dummy are compared to the inversion/eversion values that the Thor-Lx/HIII recorded.

The tests demonstrated that the kinematics of the Thor-Lx/HIII feet were similar to the angular output of the Thor-Lx/HIII. Figure 5 shows the kinematics of the feet compared to the output from the Thor-Lx/HIII for the Mitsibushi Galant, which is representative of the other vehicles. The left foot moved forward and started to rotate at 40 ms, and by 75 ms, the left foot had rotated over 25 degrees. The maximum rotation of 36 degrees occurred at 129 ms. The right foot did not start to rotate until 75 ms. Once the right foot started to rotate, it rotated 39 degrees in 30 ms. Since the rotational output from the Thor-Lx/HIII matches the kinematics of the feet, the next step was to try to

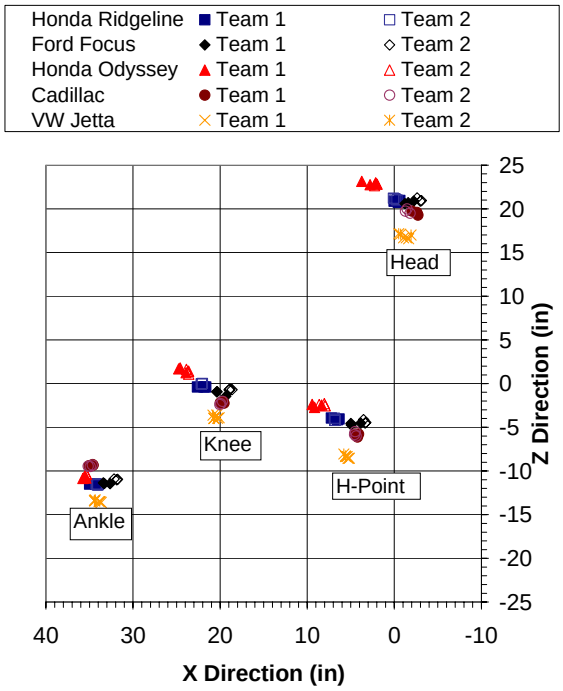


Figure 3. Dummy-based Procedure location of the driver's ankle, knee, H-Point, and head CG, with Pedals – Driver Side

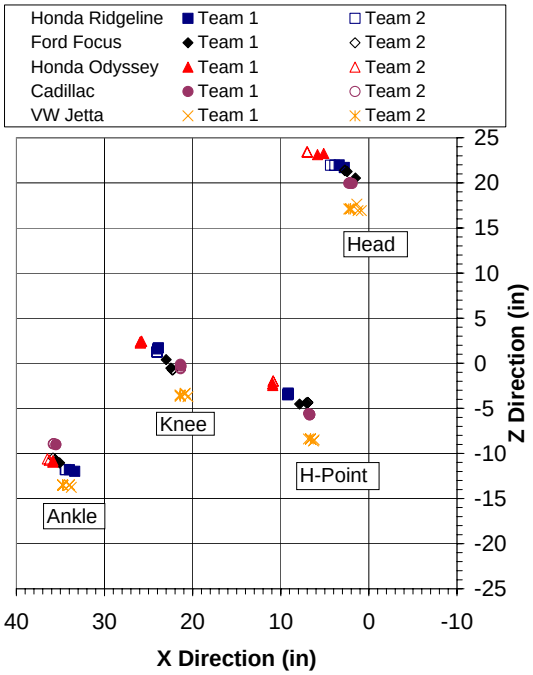


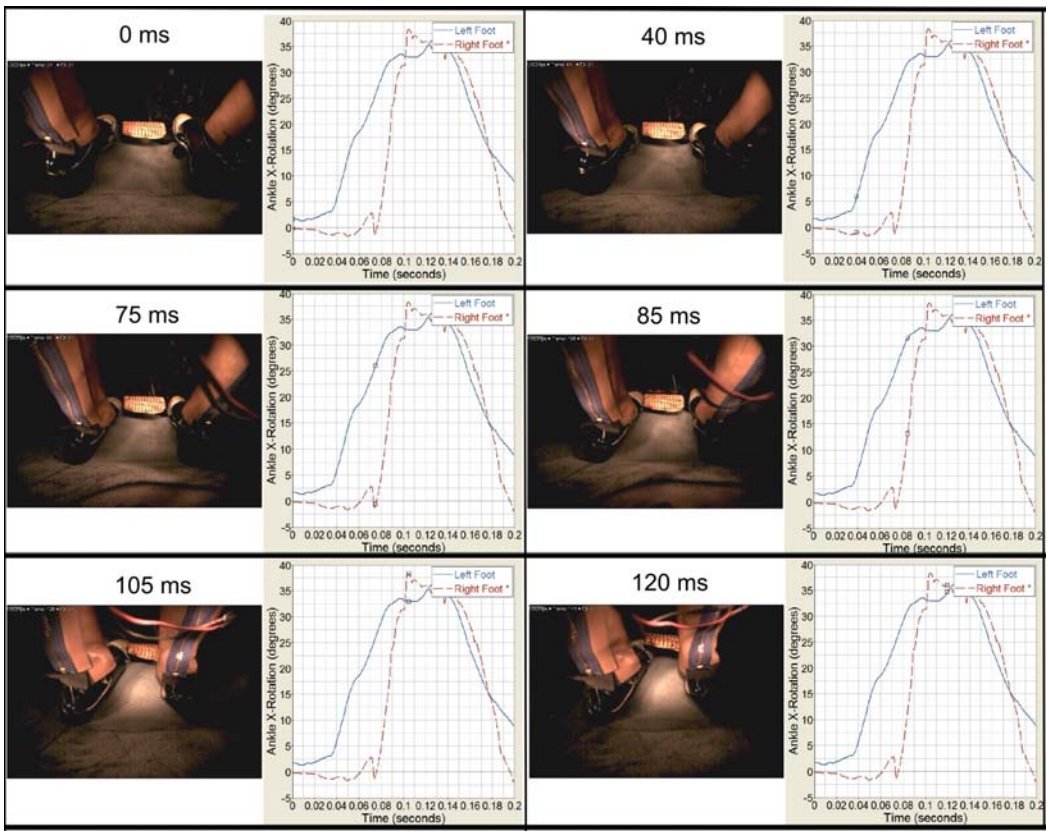
Figure 4. Mid-track procedure location of the driver's ankle, knee, H-Point, and head CG, with Pedals –Driver Side

Table 2
IAVs for FMVSS No. 208

TSTNO	MAKE	MODEL	YEAR	HIC15	HIC15 B-PILLAR	Neck Tension (N)	Neck Compression (N)	Nij	3ms Clip (Gs)	Chest Compression (mm)	Femur Left (N)	Femur Right (N)
				700	700	4170	4000	1.00	60	63	10008	10008
5654	DODGE	STRATUS	2006	114	213	717	725	0.25	31	22	2883	1028
5666	SUZUKI	VERONA	2006	187	2434	2174	222	0.34	33	24	3978	3589
5717	MITSUBISHI	GALANT	2006	157	NA	1008	715	0.29	31	23	108	133
5879	SUZUKI	FORENZA	2006	176	459	1063	790	0.37	34	26	714	482
5880	MAZDA	MAZDA6	2007	215	373	975	1792	0.56	27	18	112	77
5878	FORD	FIVE HUNDRED	2007	86	NA	1090	55	0.24	27	36	193	1

Table 3
IAVs for below the knee injuries and maximum x-dir toepan intrusion

TSTNO	MAKE	MODEL	YEAR	Left Knee Shear (mm)	Right Knee Shear (mm)	Left Tibia Force (N)	Right Tibia Force (N)	Tibia Index LL	Tibia Index LU	Tibia Index RL	Tibia Index RU	Left Ankle Rotation X (degrees)	Left Ankle Rotation Y (degrees)	Right Ankle Rotation X (degrees)	Right Ankle Rotation Y (degrees)	Max Toepan Intrusion (x-dir) (mm)
				15	15	5600	5600	0.91	0.91	0.91	0.91	35	35	35	35	
5654	DODGE	STRATUS	2006	1	1	3831	3636	0.44	0.44	1.05	0.81	14	30	38	5	111
5666	SUZUKI	VERONA	2006	18	1	3468	3907	0.60	0.64	0.65	0.73	41	33	31	14	133
5717	MITSUBISHI	GALANT	2006	25	1	1907	2405	0.27	0.37	0.67	0.53	36	11	39	0	68
5879	SUZUKI	FORENZA	2006	1	1	2078	1623	0.47	0.59	0.44	0.34	39	19	36	10	68
5880	MAZDA	MAZDA6	2007	0	1	1891	1475	0.27	0.51	0.31	0.51	36	5	22	0	24
5878	FORD	FIVE HUNDRED	2007	6	0	877	1172	0.28	0.31	0.24	0.25	30	0	32	0	27



* The right foot rotation was flipped for graphical purposes.

Figure 5. Kinematics and Thor-Lx/HIII output of the Mitsibushi Galant

determine what caused these vehicles to exceed the IARVs for ankle rotation.

The injury mechanisms that could have caused the dummy to exceed the IARVs for ankle rotation are: 1) Toepan x-intrusion, 2) Toepan resultant acceleration, and 3) Toepan geometry. It was impossible to determine the exact mechanism that caused the dummy to exceed the IARVs because all the vehicles tested had a combination of all three injury mechanisms. The following will describe each of these injury mechanisms.

The inversion/eversion IARV was exceeded for high as well as low levels of toepan intrusions. The toepan intrusion points were measured pre and post test and Figure 6 graphically shows the location of these intrusion points. When the difference in the x-displacement of the toepan for the intrusion points around the right foot for the Dodge Stratus and Mitsibushi Galant are plotted, it is shown that inversion/eversion IARV was exceeded for a vehicle with maximum x intrusion of 111 mm and also with maximum x intrusion of 68 mm (Figure 7). The results also show that a vehicle could have a higher intrusion and not exceed the inversion/eversion IARV, whereas a vehicle with low intrusion can exceed the inversion/eversion. This was shown when the intrusion points around the left foot were plotted for the Stratus and the Galant (Figure 8). The Stratus had 94 mm of intrusion and only 14 degrees of inversion/eversion, whereas, the Galant had 49 mm of intrusion and 36 degrees of inversion/eversion.

The second mechanism, toepan resultant acceleration, can cause the dummy to exceed the inversion/eversion IARV even when the toepan resultant acceleration, velocity, and dynamic displacement are similar. For example, a tri-axial accelerometer was placed by the dummy's left foot in the Mazda6 and Ford 500 tests. Figures 9 and 10 show that the two vehicles had similar resultant toepan x-acceleration, velocity, and dynamic displacement, but the Mazda6 exceeded the IARV for inversion/eversion while the Ford 500 was below the IARV for inversion/eversion.

The last mechanism, toepan geometry, seems not correlate to dummy foot rotation since different inversion/eversion IAVs can occur even when the vehicles have similar toepan geometry. The Dodge Stratus and the Ford 500 have similar toepans (Figure 11), but the difference in inversion/eversion was 16 degrees. Also, the right foot was always placed on the accelerator pedal, which is a similar surface for all vehicles tested, but the inversion/eversion ranged from 22 degrees to 39 degrees.

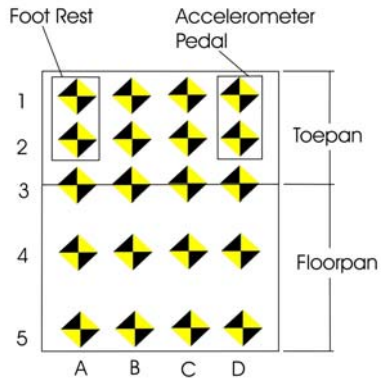


Figure 6. Intrusion points measured on the toepan and floorpan.

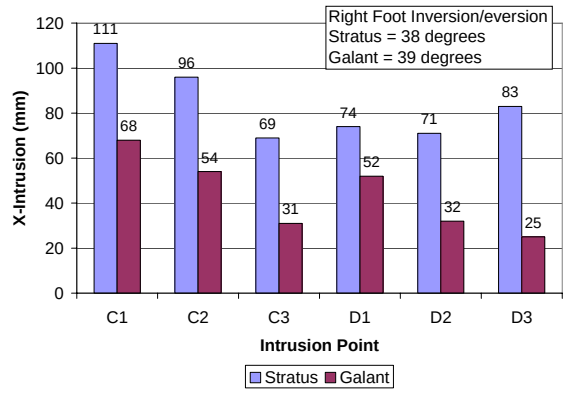


Figure 7. Comparison of x intrusion around the right foot of the HIII50LX for the Dodge Stratus and Mitsibushi Galant.

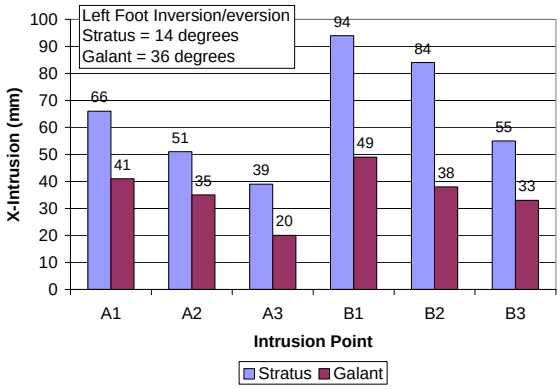


Figure 8. Comparison of x intrusion around the left foot of the HIII50LX for the Dodge Stratus and Mitsibushi Galant.

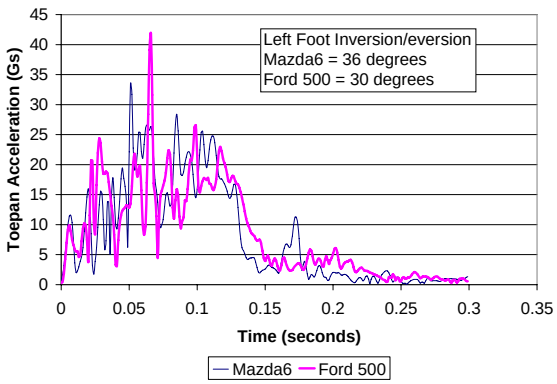


Figure 9. Footrest resultant acceleration for the Mazda6 and Ford 500.

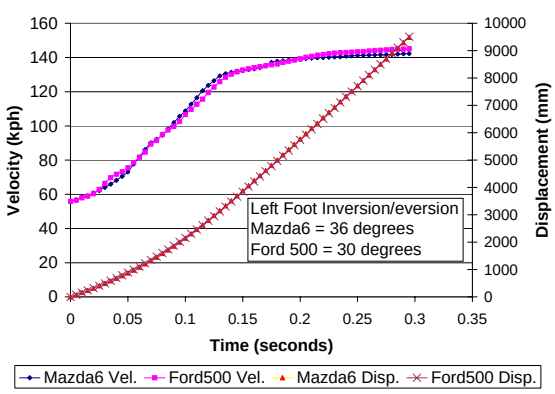


Figure 10. Resultant footrest velocity and displacement for the Mazda6 and Ford 500

Figure 11. Driver toepan pictures of (a) Dodge Stratus and (b) Ford 500

STIFFNESS CHANGES

Some concern exists that requiring all vehicles to meet the ODB test procedure might cause compatibility problems between vehicles in the fleet. This section discusses this concern.

For offset performance, the IIHS ODB test was used, which rates a vehicle using a 64 kph ODB crash test. IIHS provides a rating for a vehicle in the following categories: 1) Overall, 2) Structure and safety cage, 3) Injury measures, and 4) Restraints and dummy kinematics. Each category is given one of the following ratings: good (G), acceptable (A), marginal (M), and poor (P). IIHS also provides the model year range for which their ratings are valid. The structure and safety cage category was the most likely rating to change vehicle structures; therefore, it was the rating used for this analysis.

One metric being researched for compatibility performance is the amount of energy absorbed in the first 25 mm to 400 mm of crush in a 35 mph rigid wall test, which is symbolized as E400 (Smith, 2006). The equation for E400 is,

Initial crush energy = E400 = $F\left(X_f - X_i\right)$ (2)

Where F is the average total force exerted on the wall over the 25 to 400 mm crush interval, Xi is the initial crush (25 mm), and Xf is the final crush (400 mm). E400 was calculated using load cell wall data collected in conjunction with NHTSA's NCAP 56 kph full frontal rigid wall crash tests.

To compare the effects of offset design and compatibility, NHTSA's crash test database was searched for offset-redesigned vehicles tested by NCAP and were also rated by IIHS. In this analysis there was no effort to ensure that the NCAP vehicle tested matched exactly the vehicle tested by IIHS (i.e.

engine size, body style, and options), but only that it fell into the IIHS applicable range of model years. If there was more than one vehicle tested by NCAP in the valid model year range, then the average weight and average E400 was used. Finally, for comparison purposes, each vehicle was grouped into a different class and weight category. The weight classes for Passenger Cars (PCs) were as defined in Swanson, et al, (2003) with Sport Utility Vehicles (SUVs), Pickups (PUs), and Vans divided according to Table 4.

Figures 12 through 16 show the E400 and IIHS structure and safety cage rating for the offset redesigned vehicles. These bar charts note the weight class of the vehicle tested through a suitable suffix to the model name, including all subsequent redesigns (R1, R2, etc.). To demonstrate the relative changes in energy absorption between vehicles, these charts include an arbitrarily defined upper and lower zone for energy compatibility matching of the vehicle fleet as assumed by Saunders, et. al, (2007). At this time it is assumed that the most desirable condition is when all vehicles move into this zone and thus are able to properly share crash energy. But more research is needed to demonstrate the energy compatibility matching does not have a negative effect on self-protection and if it is the optimal metric to use for compatibility.

Table 4. Definition of vehicle classes.

	Class	Test Weight (Kg)
PCs	Mini	≤1065
	Light (Lt)	1065<w≤1292
	Compact (Com)	1292<w≤1519
	Medium (Med)	1519<w≤1746
	Heavy	>1746
Minivans	Vans	All
Pickups	PU Small	<2268
	PU Heavy	≥2268
Utility Vehicles	UV Small	≤1814
	UV Mid	1814<w≤2268
	UV Heavy	>2268

The general trend for PCs was to increase E400 and get stiffer when the structure and safety cage rating was increased for offset performance but PCs generally converged into the energy matching zone (Figures 12 and 13).

About half of the SUVs and about half of the vans tested increased E400 for the redesigned vehicles with an increase in structure and safety cage rating (Figures 14 and 15, respectively). SUVs were generally higher than the energy matching zone, and Vans were scattered all around. All PUs tested showed an increase in E400 when the structure and safety cage rating was increased (Figure 16). Small PUs were slightly higher than the matching zone, but heavy PUs are higher and moving away from the energy matching zone. It should be noted that before redesign all the heavy PUs were classified as small PUs.

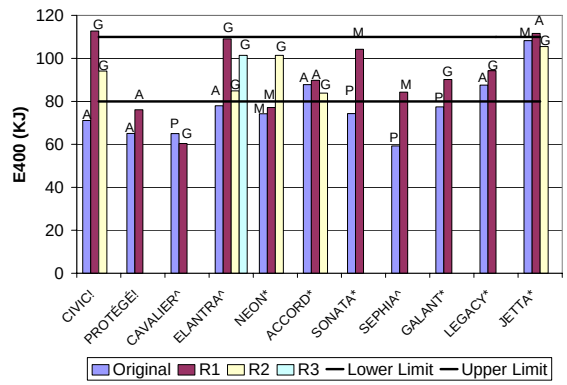


Figure 12. E400 and IIHS structure rating for smaller passenger cars. Name suffixes: !=Lt to Com, ^=Com, *=Com to Med.

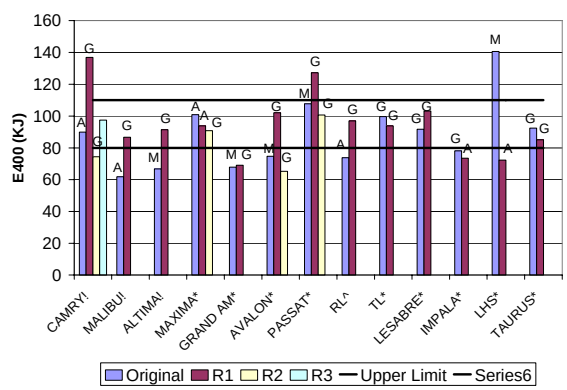


Figure 13. E400 and IIHS structure rating for larger passenger cars. Name suffixes: !=Med, *=Med to Heavy.

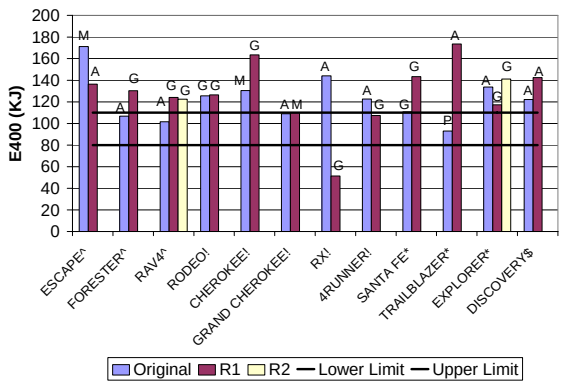


Figure 14. E400 and IIHS structure rating for SUVs. Name suffixes: ^=UV Small, != UV Mid, * UV Mid to UV Heavy, $ UV Heavy

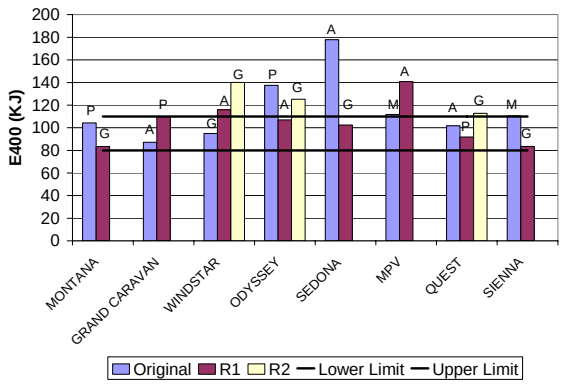


Figure 15. E400 and IIHS structure rating for Vans.

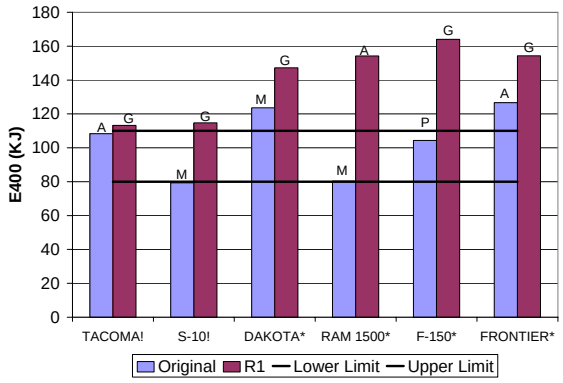


Figure 16. E400 and IIHS structure rating for PUs. Name suffixes: !=PU Small, *=PU Small to PU Heavy

FUTURE RESEARCH

The areas of research that still need to be investigated include:

1. Develop a dummy-based seating procedure for the HIII 5th percentile female with Thor-FLx retrofit legs.
2. Evaluate the repeatability of the ODB crash test procedure.
3. Continue performing crash tests to be able to calculate the benefits of the ODB test procedure.
4. Perform crash tests and simulations to explore the relationship between offset performance and compatibility performance.

CONCLUSIONS

The following conclusions can be drawn about the dummy-based seating procedure:

1. Seating procedures are available for the 50th percentile Hybrid III dummy with Thor lower legs with the seat in dummy-based or in mid-track positions.
2. The repeatability of dummy-based or mid-track procedures is similar. The foot angles at the ankle are not near neutral for the mid-track procedures. The mid-track procedure generally places the foot in dorsiflexion.
3. The final position of the ankle is similar in the longitudinal-vertical plane, for the dummy-based position with or without brake/clutch pedals.
4. The position of the head CG is controlled by the procedures for determining seat back angles.

The crash tests showed that inversion/eversion IARVs were exceeded in 5 of the 6 tests. Also, the kinematics of the Thor-Lx/HIII feet were similar to the rotational output recorded. It was impossible to determine the exact mechanism that caused the feet to exceed eversion/inversion because there was always more than one mechanism observed in the crash test.

All Pickups tested that achieved a higher rating for their structure and safety cage rating for the new design or replacement of the earlier vehicle increased its E400. Also, Pickups over 2268 kgs moved away from and higher than the energy matching zone. All other classes of vehicles had some vehicles that increased, stayed the same, or decreased for E400.

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APPENDIX A

Dummy Based Seating Procedure

Driver side positioning procedure:

Place the seat at full rear, full down, and seat cushion at mid-angle, with seat back at nominal angle specified by the manufacturer.

__1. Place adjustable pedals in the full forward position (towards the front of the vehicle.)
__N/A – the pedals are not adjustable.

__2 Locate and mark the right heel point (RHP) on the carpet.
Flat accelerator pedals: Extend a line through the axis of symmetry (that is closest to the vertical plane) of the accelerator pedal. The RHP is the intersection of that line with the floor pan.
Curved accelerator pedals: Construct a line in the side view tangent to the accelerator pedal such that the distance from the contact point on the pedal to the floor pan, along the tangent line, is 200 mm. The RHP is at the intersection of this tangent line and the floor pan

__3 Locate a longitudinal line L1 and a transverse line T1 on the floor pan through the RHP. Locate a Left Heel Point (LHP) point on the line T1 that is to the left of the seat centerline at the same distance from the seat centerline as the RHP. Locate a longitudinal line L2 through the LHP.

__4. Set the steering wheel hub at the geometric center of the full range of driving positions including any telescoping positions as determined in data sheet 14.3.

__5. Verify that the seat is in the rearmost seat track position and full down height adjustment with the seat cushion at the mid-angle with the seat back at the manufacturer's nominal seat back angle.

__6 With the seat in the rearmost, full down, mid-angle position, determine the H-point using SAE J826 and the FMVSS No. 208 leg and thigh dimensions.

__7. With the seat in the rearmost, full down, mid-angle position, place the dummy in the seat such that the midsagittal plane is coincident with the longitudinal seat cushion markings and the upper torso resting against the seat back.

__8. Rest the thighs on the seat cushion.

__9. Set the distance between the outboard knee clevis flange surfaces at 10.6 inches.
__measured distance (10.6 inches)

__10. Set the heels of the feet on the floor pan.

__11. Position the H-point of the dummy within 0.5 inch of the vertical dimension and 0.5 inch of the horizontal dimension of a point 0.25 inch below the H-point determined in step 6.
Then measure the pelvic angle with respect to the horizontal using the pelvic angle gage. Adjust the dummy position until these three measurements are within the specifications.
____horizontal inches from the point 0.25 below the determined H-point (0.5 inch max.)
____vertical inches from the point 0.25 below the determined H-point (0.5 inch max.)
____pelvic angle (20° to 25°)
The H-point and pelvic angle are not adjusted after this step.

__12. Set the left and right feet in the neutral position (longitudinal centerline of foot in the same plane as the lower leg/thigh, foot at -15 degrees +/- 2 degrees to lower leg), as determined by the output of the potentiometers at the ankle.

__13. Without moving the seat, and while keeping the right thigh and leg in the same vertical plane, set the right foot heel on Line L1. If the vehicle interior prevents the heel from reaching L1, place the heel as close to L1 as possible, while maintaining a clearance of 0.25" from the vehicle interior.

__14. Without moving the seat, and while keeping the left thigh and leg in the same vertical plane, move the left foot laterally to the left until the right edge of the foot is clear of the brake or clutch pedal by 0.25” laterally. Stop the leftward movement of the left foot if the left heel reaches on Line L2 or if the left edge of the shoe contacts the vehicle interior.

__15. Place a 25 lbs (110 N +/- 5N) weight (e.g. 110 N lead shot bag), no larger than 4” x 4”, on each knee-thigh area. The weight should be centered on the assembly-hole on the top of the knee.

__16. Raise the heels off the floor pan so that the seat can be moved forward.

__17. Using only the control that primarily moves the seat in the fore-aft direction, move the seat forward and rest the rearmost point of the right foot heel on the floor pan such that:

- the heel is on the line L1 and
- the foot is in the same plane as the lower leg/thigh, foot at -15 degrees +/- 2 degrees (about the Y- axis) to lower leg and
- foot is contacting the accelerator pedal and
- the thighs are resting on the seat cushion and
- the thigh, leg and foot are in the same vertical plane.

Note: If the heel is unable to reach line L1 because the foot contacts the vehicle interior, place the foot as close to the line L1 as possible while maintaining a gap of no more than 5 mm between the shoe and the vehicle interior.

Note: If the left foot contacts the brake or clutch pedals or the vehicle interior, then stop the forward movement of the left foot, raising the left knee off the seat cushion if needed. The pedals should not be depressed. Keep moving the seat forward until the right foot contacts the accelerator pedal.

Note: Stop the forward movement of the seat if the seat reaches its full-forward seat track position, or if the dummy contacts the steering wheel or vehicle interior like the knee bolsters.

__18. If the right foot does not reach the accelerator pedal, move the adjustable pedal until it contacts the foot. Locate a new heel point. Repeat steps 7 – 17 to re-position the seat. If the pedals are not adjustable, place the heel at the point closest to the pedal, in the same longitudinal vertical plane as the line L1.

__N/A – the accelerator pedal is not adjustable

__N/A – the accelerator pedal did not need to be moved.

__19. Remove the leg weights.

__20. Verify that the left thigh and leg are in a vertical longitudinal plane, the foot in the neutral position (longitudinal centerline of foot in the same plane as the lower leg/thigh, foot at -15 degrees +/- 2 degrees (Y-axis) to lower leg), the heel on the floor pan. Place the heel on the line L2, unless the left edge of the shoe contacts the vehicle, preventing the heel from reaching Line L2.

__21. Verify that the right foot is in the neutral position, at the lateral location determined in step 17, and is contacting the accelerator pedal. If the foot is not contacting the accelerator pedal, move the seat forward to rest the right foot on the accelerator pedal, keeping the foot in the neutral position

__22. While holding the thighs in place, push with a 50 lb force on a 3 inch diameter area of the chest that is centered 5" (127mm) vertically below the chin on the midsaggital plane of the dummy.

__23 Fasten the seat belt around the dummy.

__24 Remove all slack from the lap belt portion.

__25 Pull the upper torso webbing out of the retractor and allow it to retract; repeat this four times.

__26 Apply a 2 to 4 pound tension load to the lap belt.

____pound load applied

__27 Is the belt system equipped with a tension-relieving device?

__Yes, continue

__No, go to 29

__28 Introduce the maximum amount of slack into the upper torso belt that is recommended by the vehicle manufacturer in the vehicle owner’s manual.

__29. Place the upper arms adjacent to the torso with the centerline as close to a vertical plane as possible.

__30. Adjust the head level within ± 0.5 degrees using the seat back adjustment. Check the head angle after pushing on the chest with a 50 lb force on a 3 inch diameter area of the chest that is centered 5" (127mm) vertically below the chin on the midsaggital plane of the dummy, while holding the thighs in place, and releasing.

__31 No seat back adjustment. Adjust the neck bracket to achieve head level within ± 0.5 degrees Record neck bracket setting. _____

__32. Maintaining the head alignment as determined above, place the right hand with the palm in contact with the steering wheel at the rim's horizontal centerline and with the thumb over the steering wheel.

__33. Maintaining the head alignment as determined above place the left hand with the palm in contact with the steering wheel at the rim's horizontal centerline and with the thumb over the steering wheel.

__34. If the hands don't reach the steering wheel at the horizontal centerline, maintaining the head alignment place them at symmetric location on the wheel, below the horizontal centerline.

__35. Tape the thumb of each hand to the steering wheel by using masking tape with a width of 0.25 inch. The length of the tape shall only be enough to go around the thumb and steering wheel one time.

__36 Verify that the feet are in the neutral position (+/- 2 deg), and at lateral locations determined in step 17 (right foot) and step 20 (left foot), and the head is level (+/- 0.5 deg). Adjust and repeat until the feet position and angles and head angles are within this range.

Passenger side seating procedure:

__1. Verify that the seat is in the rearmost seat track position and full down height adjustment with the seat cushion at the mid-angle, the seat back is at the manufacturer's nominal design position for the 50th male.

__2 With the seat in the rearmost, full down, mid-angle position, seat back at the manufacturer's nominal design position for the 50th male, determine the H-point using SAE J826 and the FMVSS No. 208 leg and thigh dimensions.

__3. Place the dummy in the seat such that the midsagittal plane is coincident with the longitudinal seat cushion markings and the upper torso resting against the seat back.

__4. Rest the thighs on the seat cushion.

__5. Set the distance between the outboard knee clevis flange surfaces at 9 ¼ inches, with the leg-knee-thigh in the same vertical plane.
__measured distance

__6. Set the heels of the feet on the floor pan.

__7. Position the H-point of the dummy within 0.5 inch of the vertical dimension and 0.5 inch of the horizontal dimension of a point 0.25 inch below the H-point determined in step 2.
Then measure the pelvic angle with respect to the horizontal using the pelvic angle gage. Adjust the dummy position until these three measurements are within the specifications.
____horizontal inches from the point 0.25 below the determined H-point (0.5 inch max.)
____vertical inches from the point 0.25 below the determined H-point (0.5 inch max.)
____pelvic angle (20° to 25°)
The H-point and pelvic angle are not adjusted again after this step.

__8. Place a 25 lbs (110 N +/- 5 N) weight (e.g. 110 N lead shot bag), no larger than 4" x 4", on each knee-thigh area. The weight should be centered on the assembly-hole on the top of the knee.

__9. Set the left and right feet such that the following conditions are met after the feet are placed:
__ The foot is in neutral position.
__ The leg and thigh are in the same plane.
__ The thighs are resting on the seat cushion.
__ The heel is in contact with the floor pan.

__10 Lift the feet off the floor and set the toe towards the floor pan (Y angle = -25 +/- 2 deg). Using controls that move the seat fore-aft, move the seat forward until either foot contacts vehicle interior. Position the feet at that seat location with the heels on the floor and the feet in neutral position. If the vehicle interior prevents the feet from reaching the neutral position, place the feet as close as possible to the neutral position while maintaining a distance of 5 mm from the vehicle interior.

__11 Move the seat forward while maintaining the foot orientations (+/-2 deg) until either foot contacts the vehicle interior.

__12 Keeping the thigh-leg in the same vertical plane, move the feet apart symmetrically about the dummy midsaggital plane until the either foot contacts the vehicle interior or the knee spacing of 10.6 inches is attained, whichever comes first. Place the feet in neutral position unless contact with the vehicle interior prevents the feet from reaching the neutral position.

Check all that applies:
__ The right foot contacted a flat part of the toe board.
__ The right foot contacted the right side of vehicle interior.
__ The right foot contacted is at neutral position
__ The left foot contacted a flat part of the toe board.
__ The left foot contacted the left side if the vehicle interior.
__ The left foot contacted is at neutral position

__13. Remove the leg weights. Verify that the thighs and legs are in the same vertical longitudinal plane.

__14. While holding the thighs in place, push with a 50 lb force on a 3 inch diameter area of the chest that is centered 5" (127mm) vertically below the chin on the midsaggital plane of the dummy.

__15. Seat belt

__16 Fasten the seat belt around the dummy.

__17 Remove all slack from the lap belt portion.

__18 Pull the upper torso webbing out of the retractor and allow it to retract; repeat this four times.

__19 Apply a 2 to 4 pound tension load to the lap belt.
____pound load applied

__20 Is the belt system equipped with a tension-relieving device?
__Yes, continue
__No, go to 22

__21 Introduce the maximum amount of slack into the upper torso bet that is recommended by the vehicle manufacturer in the vehicle owner's manual.

__22. Place the upper arms adjacent to the torso with the centerline as close to a vertical plane as possible.

__23. Place the right upper arm in contact with the seat back and side of the torso. (S10.2.2)

__24. Place the left hand palm in contact with the outside of the left thigh and the little finger in contact with the seat cushion.

__25. Place the right hand palm in contact with the outside of the right thigh and the little finger in contact with the seat cushion.

__26. Adjust the head level within ± 0.5 degrees using the seat back adjustment. Check the head angle after pushing on the chest with a 50 lb force on a 3 inch diameter area of the chest that is centered 5" (127mm) vertically below the chin on the midsaggital plane of the dummy, while holding the thighs in place, and releasing.

__27 No seat back adjustment. Adjust the neck bracket to achieve head level within ± 0.5 degrees
Record neck bracket setting. _____