Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems - II

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LIST OF SYMBOLS

Symbol	Units	Description
8		Dimensionless scaling factors which are ratios between fundamental properties (length, mass, modulus, etc.) which characterize the two systems that are compared
E	MPa	Modulus of elasticity
F_f	Mpa	Failure stress of tissue
p		Probability of injury
p-value		Statistical measure of the appropriateness of the model from regression analyses
AIS		Abbreviated Injury Scale
HIC_{36}		Head injury criteria (eqn 2.1) where the time interval is limited to 36 milliseconds
HIC_{15}		Head injury criteria (eqn 2.1) where the time interval is limited to 15 milliseconds
Fx	N	Shear load measured at the upper neck load cell as specified by SAE J211 (March 1995)
Fz	N	Axial load (negative for compression, positive for tension) measured at the upper neck load cell as specified by SAE J211 (March 1995)
My	Nm	Bending moment (negative for extension, positive for flexion) at the occipital condyles as specified by SAE J211 (March 1995)
Fint	N	Intercept value for compression or tension for calculating Nij (eqn 3.1)
Mint	Nm	Intercept value for extension or flexion at the occipital condyles for calculating Nij (eqn 3.1)
Nij		Normalized neck injury criteria (eqn 3.1)
dc		Normalized central chest deflections for the human surrogate measured using chestbands

dmax		Normalized maximum chest deflections from five locations for the human surrogate measured using chestbands
As	G	3 millisecond clip value for thoracic spinal acceleration measured in the dummy or human surrogate
Aint	G	Intercept for spinal acceleration used to calculate CTI (eqn 4.2)
Ac	G	Critical acceleration limit for thoracic injury criteria
D	mm	Chest deflection measured in the dummy
Dint	mm	Intercept for dummy chest deflection used to calculate CTI (eqn 4.2)
Dc	mm	Critical deflection limit for thoracic injury criteria
UR **UC** **UL** **LR** **LL**		Five chestband measurement locations (upper right, upper center, upper left, lower right, lower left) for deflection and velocity used in the statistical analyses of thoracic injury
V	m/sec	Velocity of the chest measured either at the five location sites (UR, UC, UL, LR, LL) for the human surrogate by the chestband or at the sternum for the anthorpometric test devices
V*C **VC**	sec-1	Viscous criterion, which is the product of the chest velocity, V, and the normalized compression of the chest, D/Chest depth.
CTI		Combined Thoracic Index (eqn 4.2)

<u>Restraint system (Table 4.1)</u>

ABG	Air bag
DPL	Padded dash panel
KNEE	Knee bolster
LAP	Lap belt
2PT	2 point belt (shoulder belt without lap belt)
3PT	3 point belt
RIBFXR	Number of rib fractures (Table 4.1)

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EXECUTIVE SUMMARY

INTRODUCTION

The National Highway Traffic Safety Administration's (NHTSA) plans for upgrading the Federal Motor Vehicle Safety Standard (FMVSS) No. 208 frontal crash protection safety standard include improving protection requirements for the normally seated mid-sized adult male, as well as including additional requirements that will specify performance limits to minimize the risks from airbags to small-sized occupants and children in both normal and out-of-position seating locations. These new crash specifications will require the use of additional dummies of various sizes as well as additional performance criteria that appropriately represent injury thresholds of these additional population segments.

Based on the agency's analysis of comments received in response to the publication of the NPRM and the accompanying technical reports, the agency has made modifications to the recommended injury criteria and their associated performance limits. A detailed discussion of the comments received and the agency's analysis may be found in Appendix A. This report, which is a supplement to the previous report, "Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems", (Kleinberger, et. al, NHTSA Docket 98-4405-9) documents these modifications and the rationale.

BACKGROUND

Injury criteria have been developed in terms that address the mechanical responses of crash test dummies in terms of risk to life or injury to a living human. They are based on an engineering principle that states that the internal responses of a mechanical structure, no matter how big or small, or from what material it is composed, are uniquely governed by the structure's geometric and material properties and the forces and motions applied to its surface. The criteria have been derived from experimental efforts using human surrogates where both measurable engineering parameters and injury consequences are observed and the most meaningful relationships between forces/motions and resulting injuries are determined using statistical techniques.

Development of human injury tolerance levels is difficult because of physical differences between humans. It is further complicated by the need to obtain injury tolerance information through indirect methods such as testing with human volunteers below the injury level, cadaver testing, animal testing, computer simulation, crash reconstructions, and utilization of crash test dummies. Each of these indirect methods has limitations, but each provides valuable information regarding human tolerance levels. Due to the prohibitive number (and cost) of tests required to obtain a statistically significant sample size, it ultimately becomes necessary to consolidate the available information each of these methods provides, and apply a judgement as to what best represents a reasonable tolerance level for a given risk of injury.

Human volunteer testing has the obvious shortcoming in that testing is done at sub-injurious exposure levels. It also poses problems in that instrumentation measurements must be obtained through non-invasive attachments, volunteers are most often military personnel who may not be representative of the average adult population, and the effects of muscle tension and involuntary reflexes are difficult to ascertain. While cadaver testing is essential to the development of human injury tolerances, it also has a number of inherent variables. Cardiopulmonary pressurization, post mortem tissue degradation, muscle tension, age, gender, anthropometry, and mass are all factors which produce considerable variability in test results. Animal testing also has this problem, along with the need to translate anatomy and injury to human scales, but has the advantage of providing tolerance information under physiologic conditions. Crash reconstructions provide injury data under normal human physiological conditions, however, the forces and accelerations associated with those injuries must be estimated. Computer simulation and testing with crash test dummies provide valuable information, but these methods are dependent upon response information obtained through the other methods.

Frequently criteria are developed, based on extensive analysis, for one size dummy (e.g., an adult) and these criteria are applied and translated to other size dummies (e.g., a child) through a process known as scaling. Scaling techniques overcome the influence of geometric and material differences between experimental subjects and the subjects of interest. This technique assumes that the experimental object and the object of interest are scale models of each other and that their mass and material differences vary by relatively simple mathematical relationships. If these assumptions are met, engineering experience shows that the scaled values are good approximations of the expected values. However, the more these assumptions are not valid, the more the translated physical measurements may be distorted from their true levels.

PROPOSED HEAD INJURY CRITERIA

Existing NHTSA regulations specify a Head Injury Criteria (HIC) for the 50th percentile male. The biomechanical basis for HIC for the 50th percentile adult male was reviewed and alternatives to this function were sought. While considerable progress has been made in the capabilities of analytical finite element head/brain models to simulate the major injury mechanisms prevalent in brain injury, it was felt that it would be premature for their results to be used in this current proposed rulemaking action.

The NPRM proposed to maintain the performance limit for HIC evaluated over a maximum time interval of 36 milliseconds for the 50th percentile male, and scaled values for the other dummy sizes. Many commenters suggested using the more conservative scaled values for the HIC limits for the child dummies. The AAMA suggested limiting the HIC evaluation interval to maximum of 15 milliseconds with a performance limit of 700 for the 50th percentile male and scaled limits for the other dummy sizes.

In a Federal Register Notice issued on October 17, 1986, NHTSA indicated that it planned to limit the maximum HIC time interval to 36 milliseconds. The agency recognized that available human volunteer tests demonstrated that the probability of injury in long duration events was low, but reasoned that the agency should take a cautious approach and not significantly change the expected pass/fail ratios that the then unlimited HIC time interval provided. Evaluation, at the time, of the proposed 17 millisecond limit against various test sets from NCAP and FMVSS 208 testing available at the time was found to reduce the failure rate from 46% to 35%. This fact contributed to the agency's decision to reject the proposal of reducing the maximum HIC time interval to either 15 or 17 milliseconds without a commensurate reduction of the maximum HIC value. However, to somewhat accommodate the apparent over-stringency of the limited HIC for long duration events, the agency did propose limiting the maximum time interval to 36 milliseconds. This provision allowed the maximum average long duration acceleration to rise to a limit of 60 G's.

The agency is now proposing to evaluate the HIC over a maximum 15 millisecond time interval for all dummy sizes with a requirement that it not exceed a maximum of 700 for the adult dummies. This will simultaneously provide a equally stringent evaluation of long duration events while providing increased stringency for short duration events where biomechanical certainty is not as strong. We are proposing to change the HIC time interval to a maximum of 15 milliseconds for all dummy sizes and to revise the HIC limits by commensurate amounts, based on a scaling from the proposed new limit for the 50th percentile adult male dummy.

Both geometric and material failure scaling, coupled with engineering judgement, were employed to translate the critical HIC value to other occupant sizes. The recommended critical HIC levels for the various occupant sizes are given in Table ES.1. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the HIC_{15} limit is listed for completeness.

.**Table ES.1: Proposed Head Injury Criterion for Various Dummy Sizes**

Dummy Type	Large § Male	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Existing HIC_{36} Limit	NA	1000	N/A	N/A	N/A	N/A
Proposed HIC_{15} Limit	700	700	700	700	570	390

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

PROPOSED NECK INJURY CRITERIA

Existing NHTSA regulations specify neck injury criteria for the 50th percentile male as part of the FMVSS No. 208 alternative test, S13.2. The previous biomechanics technical paper describes in detail the derivation of the neck injury criteria, Nij, from biomechanical data (NHTSA Docket 1998-4405-9).

Comments received from various advocate groups suggested adopting conservative performance limits for the children in light of the real world injuries and deaths of children due to passenger air bags. Comments from the manufacturers in general supported the independent evaluation of neck forces and moments, rather than the evaluation of combined loads used by Nij. Three commenters (two manufacturers and one restraint manufacturer) supported Nij with a critical value of 1.4 based on practicability arguments.

Based on the comments received and the discussions at the two public meetings (see summary in Appendix E), the agency has opted to continue its support of Nij with a modified formulation and a performance limit of 1.0. The issue of neck injury, especially to out-of-position adults and children, is one of the priorities of this rulemaking and the agency would be remiss if it did not include the most accurate and up-to-date methods to assess what conditions are injurious and non-injurious. The agency continues to believe that Nij has a strong foundation in biomechanics. Furthermore, testing has shown that the performance limits proposed in the SNPRM are practicable given the time frame of this rulemaking.

The agency has made slight modifications to the formulation of Nij, referred to as the SNPRM Nij, and the scaling techniques used based upon the comments received. In general, the critical values for the SNPRM Nij are equal to or lower than the critical values proposed in the NPRM for the child test dummies. However, the SNPRM Nij critical values for the adult test dummies are about the same or slightly higher than that in the NPRM, but they are consistent with the higher performance limits (up to a value of 1.4) as discussed in the NPRM Nij which better match real world estimates of adult neck injury.

The resulting neck injury criteria, called “Nij”, propose critical limits for all four possible modes of neck loading; tension or compression combined with either flexion (forward) or extension (rearward) bending moment. The Nij is defined as the sum of the normalized loads and moments, i.e.,

$$Nij = \frac{F_Z}{F_{\text{int}}} + \frac{M_Y}{M_{\text{int}}} \qquad (3.1)$$

where F_Z is the axial load, F_{int} is the critical intercept value of load used for normalization, M_Y is the flexion/extension bending moment, and M_{int} is the critical intercept value for moment used for normalization.

The critical intercept flexion and extension moments were scaled up and down to all other dummy sizes, while the critical intercept tension and compression values were only scaled from the three year-old for the child dummies. 50th male and 5th female tension and compression values were obtained from previously developed adult cadaveric test data rather than relying on values scaled from the three year-old. The scaled critical intercept values for the various sized dummies and loading modes are given in Table ES.2. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the Nij critical intercepts are listed for completeness.

Table ES.2: Proposed Critical Intercepts for the Neck Injury Criterion, Nij, for the SNPRM

Dummy Type	Tension (N)	Compression (N)	Flexion (Nm)	Extension (Nm)
CRABI 1-year-old infant	1465	1465	43	17
Hybrid III 3-year-old child	2120	2120	68	27
Hybrid III 6-year-old child	2800	2800	93	39
Hybrid III small female	3370	3370	155	62
Hybrid III mid-sized male	4500	4500	310	125
Hybrid III large male §	5440	5440	415	166

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

PROPOSED THORACIC INJURY CRITERIA

NHTSA currently mandates regulatory limits of 60g for chest acceleration and 76 mm (3 inches) for chest deflection as measured on the Hybrid III 50th percentile male dummy. Considerable biomechanical information developed since the 1950's was used to assess potential loading thresholds for chest injuries and this information has been the basis for the existing criteria. In the previous report, the agency presented analysis of a new series of 71 highly instrumented frontal impact tests using human surrogates which were conducted over the last 5-6 years. This test series used five different restraint combinations (3-point belt, 2-point belt/knee bolster, driver airbag and lap belt, driver airbag and knee bolster, and driver airbag and 3-point belt) with a variety of crash pulses and velocity changes. The diverse capabilities of the instrumentation employed during this test series allowed the calculation and performance comparison of currently effective and potentially revised chest injury measures with the observed injury outcomes.

The analyses performed looked at a variety of statistical measures (log likelihood, p-value, gamma function, and concordant/discordant percentages) to evaluate the ability of both individual and multiple response variables to explain the observed experimental injury results. Based on these statistical measures, the analysis demonstrated that while single variables, such as peak chest acceleration, peak chest deflection, or the Viscous Criterion (V*C) advanced by one or more non-NHTSA researchers, provided a measure of prediction of injury outcome, a formulation that included both peak chest acceleration and maximum chest deflection, called the Combined Thoracic Index (CTI) appeared to provide superior predictive capability compared to all others examined. The formulation of the CTI is:

$$CTI = \frac{A_{\max}}{A_{\mathrm{int}}} + \frac{D_{\max}}{D_{\mathrm{int}}} \qquad (4.2)$$

where A_{max} and D_{max} are the maximum observed acceleration and deflection,
and A_{int} and D_{int} are the corresponding maximum allowable intercept values.

In response to the NPRM, many comments were received on the addition of CTI to the current regulations limiting chest acceleration and chest deflection independently (Appendix E). On one hand, some commenters supported the inclusion of CTI. For instance one commenter stated that CTI seems to be a more sophisticated and realistic means by which to measure chest injury. The National Transportation Safety Board (NTSB) suggested that it may be appropriate to use different CTI values for belted and unbelted occupants. On the other hand, some commenters opposed CTI because they believe that the increased stringency of CTI will lead to more aggressive air bags and/or softer vehicle structures, which would have a negative effect on real world benefits. The AAMA questioned the inclusion of a few of the data points which may be outliers in the analyses, analyzed various subsets of biomechanical data, and has reached conclusions that are different from NHTSA regarding CTI. Others recommend that further research and review are necessary.

Though the agency believes that the combination of maximum chest acceleration and deflection is a better predictor of injury than individual threshold limits for chest deflection and acceleration, there are still some questions regarding the interpretation of data used in the development of CTI. Plans for future testing are focused on answering some of these questions and increasing the number of observations in the data set. Therefore, until more data is available and a reanalysis of the larger data set is conducted to evaluate the efficacy of a CTI-based injury criteria, individual limits of maximum chest acceleration and deflection will be used for regulation purposes. However since CTI has demonstrated superior predictive capabilities than either deflection or acceleration alone, the agency has proposed to use CTI to assess the probability of injury for its economic analyses. Thus, after the biomechanical data set was modified by removing a few questionable data points and correcting data reporting errors in a few tests, a modified CTI was derived as described in Chapter 4. The revised critical CTI intercept values for the various sized occupants are shown in the Table ES.3. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the CTI intercepts are listed for completeness.

Table ES.3: Deflection and Acceleration Intercepts for Modified CTI

Dummy Type	Large Male §	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Chest Deflection Intercept for CTI (Dint)	114 mm (4.5 in)	103 mm (4.0 in)	84 mm (3.3 in)	64 mm (2.5 in)	57 mm (2.2 in)	50 mm (2.0 in)
Chest Acceleration Intercept for CTI (Aint)	83	90	90	90	74	57

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

After the publication of the previous report for the NPRM, AAMA provided an alternate thoracic injury criteria which addresses AIS\$4 thoracic injuries. The AAMA argued that since AIS\$3 injuries are predominantly associated with rib fractures and children, in general, seldom have rib fractures, it may be more appropriate to consider AIS\$4 thoracic injuries which constitute both soft tissue and bone injuries. Based on analysis using the Mertz/Weber method on the data published by Neathery (1975), AAMA recommended the chest deflection threshold in out-of-position and in-position conditions to be 64 mm for the 50th percentile male which corresponds to a 5% probability of an AIS\$4 thoracic injury.

Since this proposal is an increase in stringency from the current maximum of 76.2 mm of deflection for the 50th percentile male and further research is needed to establish the efficacy of CTI, the agency is proposing to adopt a chest deflection limit of 63 mm (2.5 inches) for the 50th percentile male. This would be in addition to the current performance limit of 60 g's for the 3-msec clip value of resultant chest acceleration. These individual deflection and chest acceleration performance limits have been scaled to the various dummy sizes and are shown in Table ES.4. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the chest performance limits are listed for completeness.

Table ES.4: Performance Limits for Chest Deflection and Chest Acceleration Evaluated Independently

Dummy Type	Large Male §	Mid-Sized Male	Small Female	6 Year Old Child	3 Year Old Child	1 Year Old Infant
Chest Deflection Limit for Thoracic Injury (Dc)	70 mm (2.8 in)	63 mm (2.5 in)	52 mm (2.0 in)	40 mm (1.6 in)	34 mm (1.4 in)	30 mm** (1.2 in)
Chest Acceleration Limit for Thoracic Injury Criteria (Ac)	55	60	60*	60	55	50

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

* Although geometric scaling alone would predict higher Ac values for females, it is believed that lower bone mineral density would offset this effect. Therefore, the acceleration tolerance values for small females are kept the same as for mid-sized males.

** The CRABI 12 month old dummy is currently not capable of measuring chest deflection.

PROPOSED LOWER EXTREMITY INJURY CRITERIA

While a great deal of research is currently underway both in experimental activities to determine biomechanical tolerance criteria as well as developing enhanced lower extremities for the dummies, both sets of activities are not ready for inclusion in these recommendations. Because femoral fractures in children are not a significant problem in automotive crashes, the NPRM recommended to use femur load only for the adult dummies. The 10 kN limit for the axial femur load on the Hybrid III 50th percentile male dummy was maintained and NHTSA proposed a 6.8 kN limit, obtained by geometric scaling, for the 5th percentile female dummy.

In response to the NPRM, commenters supported the inclusion of performance limits for femoral compressive loads for the 5th percentile female dummy specified in the NPRM in addition to maintaining the currently specified value for the 50th percentile male dummy. Furthermore, AAMA proposed adding femoral compressive load performance criteria of 2310 N for the 6 year-old dummy. The National Transportation Safety Board (NTSB) recommended that tolerance levels of lower extremities need to be further investigated and validated. NTSB also suggested that the NHTSA consider dummies such as advanced lower extremity (ALEX, now renamed the THOR-LX) dummy for future incorporation into the standards.

Although the NHTSA agrees with the AAMA that femoral compressive load limits for the six year-old dummy are important to consider, the SNPRM does not specify such limits because the testing configurations specified in the SNPRM for the six year-old dummy do not impose substantial loading on the lower extremities. NHTSA is also continuing the development of an advanced lower extremity test device, the THOR-LX, and continues to sponsor experimental impact injury research to determine the mechanisms and tolerances of the lower extremities, including the foot, ankle and leg. When this effort is complete, it is anticipated that this research will be incorporated into future safety standards.

SUMMARY AND RECOMMENDATIONS

This report presents NHTSA's analysis of available biomechanical data to define mathematical relationships that can discriminate the mechanical impact conditions under which various portions of the human body will or will not be injured. In those cases where the data were sparse or not directly applicable, accepted engineering techniques, such as scaling and engineering judgement, were employed to both develop and extend existing knowledge to all of the various occupant sizes being considered for the proposed rulemaking action. Table ES.6 summarizes the proposals that are a result of this effort, and are believed to represent the best characterization of injury criteria available at this time. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the performance limits are listed for completeness.

Table ES.6: Summary of Recommended Injury Criteria for the SNPRM

Recommended Criteria	**Large§ Male**	**Mid-Sized Male**	**Small Female**	**6 YO Child**	**3 YO Child**	**1 YO Infant**
Head Criteria: HIC (15 msec)	700	700	700	700	570	390
Neck Criteria: SNPRM Nij	1.0	1.0	1.0	1.0	1.0	1.0
Critical Intercept Values						
Tension and Compression (N)	5440	4500	3370	2800	2120	1465
Flexion (Nm)	415	310	155	93	68	43
Extension (Nm)	166	125	62	39	27	17
Thoracic Criteria						
1. Chest Acceleration (g)	55	60	60	60	55	50
2. Chest Deflection (mm)	70 (2.8 in)	63 (2.5 in)	52 (2.0 in)	40 (1.6 in)	34 (1.4 in)	30* (1.2 in)
Lower Ext. Criteria: Femur Load (kN)	12.7	10.0	6.8	NA	NA	NA

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

* The CRABI 12 month old dummy is not currently capable of measuring chest deflection.

The following chapters delineate in much greater detail the available biomechanical data, its sources, and the procedures used to derive the proposed recommended performance limits for each major body area and occupant size. Appendix A presents a summary of the responses to the Notice of Proposed Rulemaking for FMVSS No. 208 and other opportunities for public comment on proposed injury criteria. Appendices B, C, and D offer extensive examples of the application of the various proposed injury criteria to available test data. Appendix E discusses statistical analysis procedures for developing injury risk curves from biomechanical test data. Appendix F summarizes the development of age-dependent neck scale factors. Appendix G provides the source files for a software program to calculate the Nij Neck Injury criteria.

Chapter 1
Introduction

Many researchers from around the world have contributed to the current base of knowledge of biomechanics. Over a century ago, researchers conducted tests to determine the strength of various biological tissues. (Duncan, 1874 and Messerer, 1880) Research into the safety of automotive occupants has been actively pursued for decades. Current issues and experimental results are presented every year at international conferences dedicated to biomechanics research. One of these annual meetings, the Stapp Car Crash Conference, has recently celebrated its 43rd anniversary. In developing the proposed injury criteria, the NHTSA's National Transportation Biomechanics Research Center (NTBRC) has drawn extensively from existing published research. Existing data from human cadavers, animal subjects, and to a limited degree live volunteers have been extensively analyzed during the process of developing the proposed injury criteria. Discussion of these previous experimental studies will be included in the sections for each individual body region.

In this introduction, two techniques - scaling and statistical analysis - that are used in developing the proposed injury criteria are summarized.

1.1 SCALING TECHNIQUES

Often, data can be collected for a specific type of vehicle occupant under a given loading condition, (e.g., an adult male), but data cannot be collected on other types of occupants. This is clearly evidenced by the paucity of biomechanical data available for children. Given these circumstances, biomechanics researchers must turn to scaling techniques and engineering judgement to develop injury criteria for other size occupants (e.g., children).

The type of scaling most commonly used in automotive applications is dimensional analysis. For mechanical systems in which thermal and electrical effects are absent, this technique allows the unknown physical responses of a given system to be estimated from the known responses of a similar system by establishing three fundamental scaling factors that are based on ratios between fundamental properties that characterize the two systems.(Newton, 1687, Langhaar, 1951 and Taylor, 1974) For structural analysis, the three fundamental ratios are length, mass density, and modulus of elasticity or stiffness. The scaling ratios for other variables of interest are based on the fundamental ratios.(Melvin, 1995) The three dimensionless fundamental ratios are defined as

Length Scale Ratio: $8_L = L_1 / L_2$

Mass Density Ratio: $8_D = D_1 / D_2$

Modulus of Elasticity Ratio: $8_E = E_1 / E_2$

where the subscripts 1 and 2 refer to the subjects to be scaled to and from, respectively. Scale factors for all other physical quantities associated with the impact response of the system can be obtained from these three dimensionless ratios.

When scaling data between adult subjects it is generally assumed that the moduli of elasticity and mass densities are equal for both subjects, and that the scale factors for these quantities are equal to one. The effect of this assumption is that all the physical quantities can be scaled as functions of the basic length scale ratio, 8_L, assuming geometric similitude. When scaling data from adults to children, or between children of various ages, differences in the moduli of elasticity must be considered to account for the anatomic structural immaturity in children. Assuming mass density to be constant for all subjects ($8_D = 1$), the following scale factors can be formed. (Melvin, 1995)

Length Scale Factor: $8_L = L_1 / L_2$

Mass Scale Factor: $8_m = (8_L)^3$

Modulus of Elasticity Scale Factor: $8_E = E_1 / E_2$

Time Scale Factor: $8_T = 8_L / (8_E)^{1/2}$

Acceleration Scale Factor: $8_A = 8_E / 8_L$

Force Scale Factor: $8_F = (8_L)^2\ 8_E$

Moment Scale Factor: $8_M = (8_L)^3\ 8_E$

HIC Scale Factor: $8_{HIC} = (8_E)^2 / (8_L)^{1.5}$

The generalized scaling relationships listed above are termed equal stress scaling and allow one to infer what the response of one subject size is based on measurements of another subject size. For example, if one subject has twice the length ($8_L = 2$) and three times the modulus ($8_E = 3$) as another, a force which is 12 times as great would be necessary to produce the same stress in the two subjects. AAMA noted in their response to the NPRM that by scaling failure threshold levels according to the modulus of elasticity scale factor, the implicit assumption is that the ratio of failure strains is equal to one. However, failure strain and stress levels of biological tissue may be age dependent. Therefore, it is more appropriate to scale failure threshold levels by the failure stress (F_f) or strength ratio. Accordingly, failure stress ratio was used in the scaling of threshold levels between various dummy sizes.

Length Scale Factor: $8_L = L_1 / L_2$

Mass Scale Factor: $8_m = (8_L)^3$

Failure Strength Scale Factor: $8_{s\,f} = F_{f1} / F_{f2}$

Acceleration Scale Factor: $8_{A} = 8_{Ff} / 8_{L}$

Force Scale Factor: $8_{F} = (8_{L})^{2}\, 8_{Ff}$

Moment Scale Factor: $8_{M} = (8_{L})^{3}\, 8_{Ff}$

HIC Scale Factor: $8_{HIC} = (8_{Ff})^{2.5} / (\lambda_{L})^{1.5}$

1.2 STATISTICAL ANALYSIS TECHNIQUES

Because mechanical surrogates of humans (crash test dummies), rather than living humans, are used in crash tests to evaluate the safety attributes of vehicles, relationships between measurements of engineering variables made on the dummy and the probability of a human sustaining a certain type and severity of injuries are needed. The process to develop these relationships, commonly called injury criteria, is to conduct a series of experimental tests on highly instrumented biologically realistic human surrogates, such as cadavers, that expose them to crash conditions of interest. Measurements of engineering variables, such as forces, velocities, deflections, and accelerations, are made to mechanically characterize each impact event. Necropsy results are used to document the concomitant injuries. The data are entered into an appropriate database for analysis. The following procedures are considered by the NTBRC to provide the most meaningful relationships and thus were applied as indicated.

First, the level or severity of injury in each test was classified using the 1990 AIS manual. Each test in the data set was then assigned to one of two categories: (1) “no injury” representing the absence of injuries or minor injuries of AIS<3, or (2) “injury” representing serious injuries of AIS$3. Logistic regression was then used to develop injury criteria models where the mathematical relationship between the dichotomous dependent variable (“injury” or “no injury”) and various independent measured or calculated variables such as spine acceleration were estimated. In logistic regression, a “null hypothesis” is initially made assuming that there is no relationship between the dependent injury variable and the candidate independent variable under study. The goodness of fit of the model is determined by examining the -2 log-Likelihood Ratio (-2log(LR)), which is a measure of the probability that the independent variable(s) explains the available outcomes. The -2log (LR) is used to test the null hypothesis and provide measures of rejection of the null hypothesis call “p-values”. Higher values of -2log(LR) and lower p-values indicate that the model provides a better fit to the data.

Model building strategies and goodness of fit measures outlined by Hosmer and Lemeshow (1989) were used to develop the injury criteria models as well as for comparing their relative predictive ability. The Goodman-Kruskal Gamma of rank correlation was used for assessing the predictive ability of the model. Similar to R^2 in regression analysis, a Gamma value of 1 indicates perfect predictive ability while a value of 0 indicates no predictive ability of the model. The predictive ability of the model can also be assessed by the percentage of concordance and discordance. A greater percentage of concordance indicates better predictive ability of the model.

Much of the data used in this analysis have been previously analyzed using the Mertz/Weber method.(Mertz, 1996). This method uses only two data points from the available experimental data set to define the range of overlap region between "non-injury" and "injury", that is, the lowest value associated with "injury" and the highest value associated with "non-injury". Based on these two points, a modification of the "median rank" method is used to determine the mean and standard deviation of an assumed cumulative normal distribution function to explain the probability of an injurious event occurring. No statistical goodness of fit measures are used to guide the analysis or provide evaluations of the resulting predictive relationships.

Because of the considerable methodological differences between these two methods, significantly different functions can result from the data set depending on whether the Mertz/Weber method or logistic regression technique was employed. Therefore, because logistic regression technique uses the entire available experimental data set, uses the widely accepted statistical concept of "maximum likelihood" to obtain its results, and provides established statistical measures to evaluate absolute and relative predictive capabilities of the resulting relationships, logistic regression was used for all analyses performed in the development of cervical and thoracic injury criteria and tolerance limits discussed in the previously published report on injury criteria.

In response to the previously published agency report, the AAMA commented that the statistical methods used by the agency are invalid and that "no significant mathematical or experimental foundation was given". The logistic regression methods used to develop CTI are well established methods used in epidemiological research and in drug studies which are well documented in many books and is explained in detail by Kuppa (1998). Other references may be found in Hosmer and Lemeshaw (1989), Menard, and Kleinbaum, et al (1982). Methods of analyses using regression methods such as ANOVA and logistic regression have already been proven to be effective methods for data where the dependent variable is nominal (such as injury outcome). Therefore, it was considered unnecessary to go into the mathematical details of this procedure. Logistic regression is extensively used in determining appropriate dose levels in drug effectiveness studies. The process of determining injury threshold levels using sled test data follows a similar methodology.

The relative merits of the various statistical methods were discussed at the biomechanics public meeting held on April 20, 1999. Simulation studies showed that logistic regression using the maximum likelihood method is able to predict the population parameters more accurately than other methods such as the Mertz-Weber median rank method or the Certainty Method, as shown in Appendix E. Thus, the agency continues to support logistic regression techniques as the most appropriate method of analysis and also uses this technique for the analyses discussed in the current report.

Chapter 2
Head Injury Criteria

2.1 BACKGROUND

Motor vehicle crashes are responsible for nearly one half of the more than fifty thousand who die and approximately one million who are hospitalized as a result of head injury in the United States (Bandak et al, 1996). Head injury continues to be a leading cause of death and disability although considerable advancement in the understanding of head injury mechanisms and the introduction of airbag restraint systems has resulted in the reduction of the number and severity of head injuries. In spite of these advancements the only injury criteria in wide use is the Head Injury Criterion (HIC), which was adopted over twenty-five years ago.

This Head Injury Criterion has a historical basis in the work of Gadd (1961) who used the Wayne State Tolerance Curve (WSTC) to develop what eventually became known as the Gadd severity index GSI (1966). The WSTC is based on the average resultant translational head acceleration. It evolved from the early work of Gurdjian and co-workers (1955) who used the clinically observed prevalence of concomitant concussions in skull fracture cases (80% of all concussion cases also had linear skull fractures (Melvin, 1993)) to relate cadaver impacts to brain injury. Gurdjian and co-workers concluded that by measuring the tolerance of the skull to fracture loads one is effectively inferring the tolerance to brain injury. Lissner and co-workers (1960) later developed a relationship between the magnitude of the translational anterior-posterior acceleration and the load duration that became known as the WSTC. Versace (1971) proposed a version of the current HIC in 1971 as a measure of average acceleration that correlates with the WSTC. HIC was then proposed by NHTSA as a replacement for the GSI in FMVSS No. 208 and is computed according to the following expression:

$$HIC = \max\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}(t_2 - t_1)$$

where t_2 and t_1 are any two arbitrary times during the acceleration pulse. Acceleration is measured in multiples of the acceleration of gravity (*g*) and time is measured in seconds. On October 17, 1986, NHTSA proposed to limit this HIC time interval to 36 milliseconds. The agency recognized that available human volunteer tests demonstrated that the probability of injury in long duration events was low, but reasoned that the agency should take a cautious approach and not significantly change the expected pass/fail ratios that the then unlimited HIC provided. Evaluation, at the time, of the proposed 17 millisecond limit against various test sets from NCAP and FMVSS 208 testing available at the time was found to reduce the failure rate from 46% to 35%. This contributed to the agency's decision to reject the proposal of reducing the HIC time interval to 15 to17 milliseconds without a commensurate reduction of the maximum HIC value. However, to somewhat accommodate the apparent over-stringency of the limited HIC for long duration events, the agency did propose limiting the maximum time interval to 36 milliseconds. This provision allowed the maximum average long duration acceleration to rise to a limit of 60 G's.

The agency is proposing to evaluate the HIC over a maximum 15 millisecond time interval for all dummy sizes with a requirement that it not exceed a maximum of 700 for the 50th percentile male and the 5th percentile female. This will simultaneously provide a equally stringent evaluation of long duration events while providing increased stringency for short duration events where biomechanical certainty is not as strong. We are proposing to change the HIC time interval to a maximum of 15 milliseconds for all dummy sizes and to revise the HIC limits by commensurate amounts, based on a scaling from the proposed new limit for the 50th percentile adult male dummy.

The HIC limits proposed in the NPRM reflected a scaling methodology that included both geometrical and material property scaling using the properties of the cranial sutures. This method was based on the assumption that the pediatric skull deformation is controlled by properties of the cranial sutures, rather than the skull bones. Comments received in response to the NPRM and at a public meeting held on April 20, 1999 focused primarily on two issues: (1) the time duration used for the computation of HIC and (2) the scaling of HIC for the child dummies. In general, commenters urged that more conservative values for HIC should be adopted for the child dummies and especially for the 12-month-old CRABI infant dummy. Commenters cited differences in structure between the compliant infant skull with soft cranial sutures and the adult skull in addition to the uncertain tolerances of the infant's brain. AAMA recommended that the duration for the HIC computations be limited to 15 milliseconds with a limit of 700 for the 50th percentile adult male dummy, which is consistent with Canadian Motor Vehicle Safety Standard No. 208. The basis for AAMA's recommended 15 millisecond duration was that, in the original biomechanical skull fracture data from which HIC was derived, no specimen experienced a skull fracture and/or brain damage with a HIC duration greater than 13 milliseconds. AAMA also argued that HIC36 overestimates the risk of injury for long-duration head impacts with air bags. That organization cited a study where human volunteers who were restrained by air bags experienced HIC36 greater than 1000 and did not experience brain injury or skull fracture.

Based on a recent analysis of 295 NCAP tests, shown in Figure 2-1, the stringency of HIC_{15} of 700 and HIC_{36} of 1000 appear to be equivalent for long duration events because while HIC_{15} produces a lower numerical value for long duration events, its lower threshold, 700, compensates for this reduction. Of the 295 NCAP tests examined, 260 passed and 18 failed both criteria, 10 tests that failed HIC_{15} passed HIC_{36}, while 7 tests that failed HIC_{36} passed HIC_{15}. Thus, the two criteria and associated thresholds offer approximately the same stringency for long durations events. For short duration events, where either criteria would produce the same numerical value, HIC_{15} with its proposed 700 threshold is more stringent. The agency believes that this increased stringency (conservativeness) for short duration impacts is justified in light of the HIC function's somewhat uncertain relationship with brain injury and the extreme measures employed to scale the adult threshold of 700 to small children and the 5th female. Thus, the agency proposes to employ a 15 millisecond time interval whenever calculating the HIC function and limiting the maximum response of the adult dummies to a value of 700 and suitably scaling the performance limits for the child dummies.

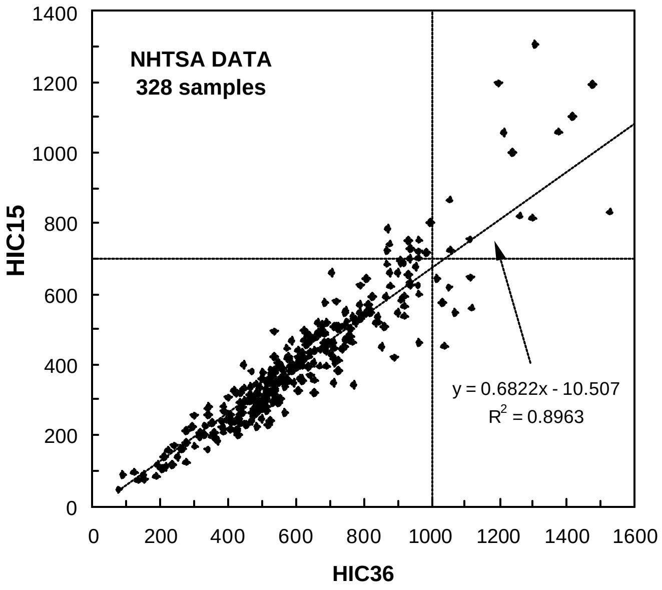

Figure 2-1: Comparison of HIC_{15} and HIC_{36} for NCAP data.

Comparisons were made between HIC_{15} and HIC_{36}. For sinusoidal pulses (Figure 2-2), HIC_{15}=700 gives lower peak acceleration limit for short duration pulses but higher peak acceleration for long duration (>50ms) pulses. HIC_{15}=500 gives lower peak acceleration limit for pulses with duration up to75ms and the same limit after that.

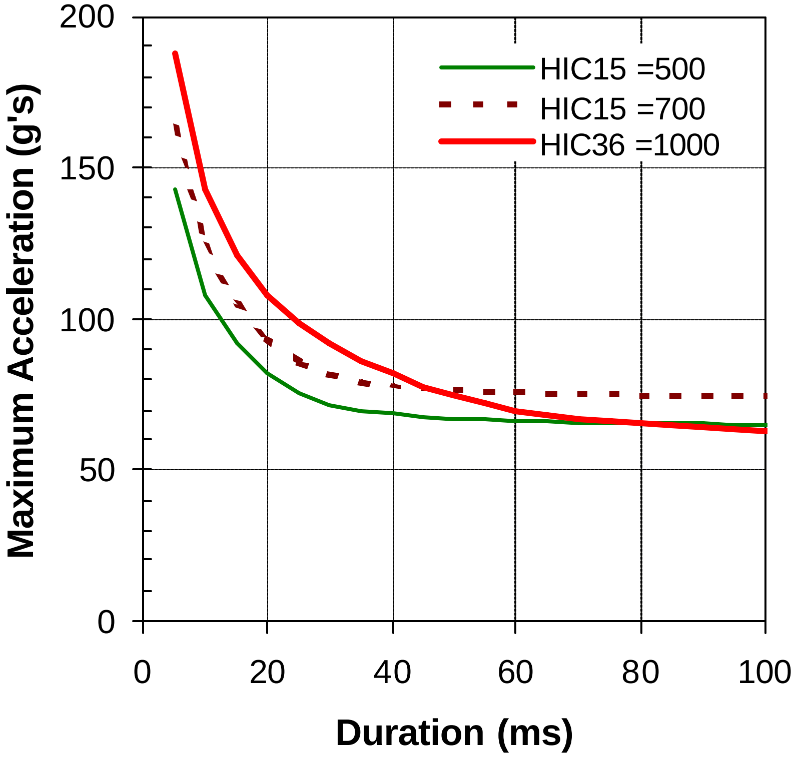

Figure 2-2: Comparison of HIC_{15} and HIC_{36} for theoretical head acceleration pulse which is a half-sine wave

2.2 SCALING HIC TO VARIOUS OCCUPANT SIZES

The head structure for the whole dummy family used in FMVSS 208 is essentially a padded rigid aluminum shell that does not deform as does the human skull under loading. The amount and type of deformation in the human skull, for a particular loading, varies significantly with age with marked difference between very young children and adults. Scaling for these effects in various occupant sizes requires knowledge of the geometric, material, and rate response differences in the populations. The paucity of available data on the properties and biomechanical response of the human head as a function of age makes the scaling task very difficult. McPherson and Kriewall (1980) reported a study of the mechanical properties of fetal cranial bone. The study included bending tests on samples of skull bone from fetuses and one six year old child. They obtained tensile moduli scaling factors, for the six year old, of 0.59-0.79, depending on the direction, compared to the adult. Results reported by Melvin (1995) indicated that the stiffness ratio with respect to the adult value was 0.243 for the newborn skull and 0.667 for the six year old.

A scaling factor for HIC can be written as $\lambda_{HIC} = (\lambda_E)^2 / (\lambda_L)^{1.5}$ where λ_E is the material scale factor and λ_L is the head length scale factor. To summarize the agency's development of HIC scaling factors presented in the previous report (NHTSA Docket 1998-4405-9), three different scaling methods were investigated to obtain HIC values for the various occupant sizes. Results from these scaling methods are shown in Table 2-1. Geometric scaling alone predicted higher tolerance to head acceleration for a child than for an adult. For example, the HIC_{36} scale factor for a 12 month old dummy, assuming $\lambda_E = 1$, would be 1.34. Thus, the scaled HIC_{36} limit for a 12 month old is 1344. Melvin (1995) used bone modulus as a scale factor in obtaining results that give relatively low HIC values for children, for instance 138 for a 12 month old. Here, NHTSA's used Melvin's approach but with a different head length scale factors obtained from a different source (NHTSA, 1996). The third method for scaling HIC used in the previous report (NHTSA Docket 1998-4405-9) assumes that pediatric skull deformation is controlled by the properties of the cranial sutures, rather than the skull bones. Using tendon strength as a surrogate for suture stiffness leads to a HIC_{36} limit for a 12 month old of 660, which falls in between the previous two methods. This method was used to scale the HIC_{36} limits proposed in the NPRM. Table 2-1 shows the proposed HIC_{36} values for each dummy size. Although a scaled HIC_{36} value of 1081 was obtained for the six year old, a value of 1000 was maintained to avoid having a higher threshold for a child than for an adult, given the uncertainties in the scaling process. The proposed limit for the three year old was rounded up from 894 to 900. The limit for the 12 month old was rounded up from 659 to 660.

Table 2-1. Head Injury Scale Factors and Criteria.

	Mid-Sized Male	**Small Female**	**6 Year Old**	**3 Year Old**	**12 Month Old**
Head Length Scale Factor	1.000	0.931	0.899	0.868	0.821
Bone Modulus Scale Factor	1.000	*	0.667	0.474	0.320
Tendon Strength Scale Factor	1.000	*	0.960	0.850	0.700
Geometric Scaling Only	1.000	1.113	1.173	1.237	1.344
Material Scaling with Bone Modulus	1.000	1.000*	0.522	0.278	0.138
Material Scaling with Tendon Strength	1.000	1.000*	1.081	0.894	0.659
Material Scaling with Failure Strength (AAMA)	1.000	1.113	1.033	0.812	0.555

* Data comparing the modulus and strength of female anatomic structures to male are not available at this time. Although geometric scaling alone would predict higher tolerance values for females, it is believed that lower bone mineral density would offset this effect. Therefore, the tolerance values for small females are kept the same as for mid-sized males.

In response to the NPRM, the AAMA proposed that the bulk modulus of the brain should be used as the material scaling factor rather than the bone modulus. Based on a simple analysis of the skull, brain and flesh as a series of springs, Irwin and Mertz calculated that the bulk modulus of the brain has a more significant effect on the overall stiffness of the skull and brain than the bone modulus (Irwin and Mertz, 1997). The AAMA proposed using the following scaling ratios,

Time Scale Factor: $8_t = 8_L$
Acceleration Scale Factor: $8_{af} = 8_{Ff}^{\ 2} / (8_L)$
HIC Scale Factor: $8_{HIC} = (8_{Ff})^{2.5} / (8_L)^{1.5}$

where 8_L is the ratio of head lengths and 8_{Ff} is the ratio of failure stress of brain tissue with age. Since there are no data on the variation of failure stress of brain tissue with age, Mertz made the assumption that its variation is the same as the variation of calcaneal tendon noted by Melvin (1995). The AAMA also proposed for ease of computation to use a constant maximum time interval of 15 milliseconds for the evalution of HIC, although the scaling techniques would suggest that the maximum time interval would also be different for the various dummy sizes, ranging from 12.3 to 15 milliseconds. The resulting scale factors, shown in Table 2-1 are very similar to that obtained by using the tendon strength as the material property.

After review of the various comments received, the agency conducted further analyses using the finite element method as the basis for an alternate approach to the aforementioned techniques to scale HIC values for different sized occupants. This approach utilized salient geometric and material characteristics and features specific to 3 year old, 6 year old, and adult head approximations. Skull strain response was used as the biomechanical basis for determining the different HIC values for the various occupant sizes. This process is inherently approximate and is highly dependent on material and failure descriptions for the various bone types. The availability of such values in the literature is sparse in the case of adult cranial bone and nearly nonexistent for pediatric bone and suture tissue.

The approach involved the construction of two idealized spherical finite element models for each age. The first is a proportionally layered deformable model of the head and the second is a rigid model representing the dummy head equivalent for that age. The deformable model was dropped until some biomechanical threshold was exceeded. The dummy head model was then dropped from the same height to obtain the associated HIC value noting that the dummy models were calibrated against drop requirements for physical dummy heads. Each model was based on actual human dimensions and weights for that age. The thickness of the skull, and scalp layers were not scaled from size to size but rather chosen to represent actual dimensions reported for the various sized occupants. The material parameters were also chosen to represent specific reported values from the literature and were not scaled by a generalized scaling relationship to the various occupant sizes. The bones of the skull are joined together by joints called sutures. For the first year and a half after birth these sutures develop into fibrous connective tissue tying the bones together and by the end of this period closing skull openings such as the fontanelle. Between the ages of 3 and six these joints go through an ossification process that essentially transforms them from connective tissue to bone. The effect of these sutures on the breaking strain of 1 year old skull is not considered explicitly in the models but is accounted for in the overall stiffness of the skull. This is an important point since variations in the threshold strain values result in large variations in the resulting HIC. More data on child skull stiffness and breaking strain is needed. The failure level for the deformable models was determined based on a value of maximum principle strain in the skull. The value for this strain in the adult has been reported to be about 0.5% (Wood, 1971). An estimation for the same value in the 6 year old skull was taken to be 0.5% and the breaking strain values for the 3 and 1 year old children were taken as 1% and 2% respectively. These values are summarized in Table 2-2.

Table 2-2: Finite Element Analysis (FEA) Based Scaling Techniques for HIC 15.

	Breaking Strain	**Dummy Based HIC $_{15}$ Range Based on FEA**	**Scaled HIC $_{15}$ Using AAMA Techniques**
1 YO	2%	200-300	390
3 YO	1%	300-400	570
6 YO	0.5%	500-600	723
Adult	0.5%	700	700
Small Female	0.5%	700	779
Mid-Sized Male	0.5%	700	700

The agency has considered the proposal by the AAMA for scaling HIC_{15} according to tissue failure stresses and has found it to be approximately equivalent to both the scaled HIC_{15} values determined through finite element analysis and the scaling technique employed in the NPRM which uses tendon strength. In addition since there was a consensus among the members of the AAMA to adopt the scaling technique based on tissue failure stresses, the agency proposes to use this method for scaling the HIC_{15} performance limits. However, the AAMA proposed performance limits higher than 700 for the six year old child and for the 5th percentile female. In light of the uncertainties in the scaling techniques, the agency believes it would not be prudent to allow a higher limit for a child than for an adult, and thus propose that the performance limit for the six year old be set at a value of 700 for $HIC_{15.}$ Furthermore, since the biomechanical data used to develop HIC consisted of both male and female skulls of various sizes and since head size is not well correlated to body size, the agency is proposing a single value for HIC_{15} of 700 for all all adult dummies. The agency's recommended performance limits are summarized in Table 2-3. Although the large male Hybrid III dummy is not included in the proposed testing for the advanced air bag SNPRM, the HIC_{15} limit is listed for completeness.

Table 2-3: Proposed Head Injury Criterion for Various Dummy Sizes

Dummy Type	**Large § Male**	**Mid-Sized Male**	**Small Female**	**6 Year Old Child**	**3 Year Old Child**	**1 Year Old Infant**
Proposed HIC_{15} Limit	700	700	700	700	570	390

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

2.3 HEAD INJURY RISK ANALYSIS

Prasad and Mertz (1985) analyzed available test data from human surrogates to determine the relationship between HIC and injuries to the skull and brain. Methodologies used to analyze the brain injury data had a number of limitations, and resulted in a risk curve nearly identical to the skull fracture injury risk. Skull fracture data consisted of head drop tests on both rigid and padded flat surfaces (Hodgson, 1977), sled tests against windshields (Hodgson, 1973), and helmeted drop tests (Got 1978, Tarriere 1982). The combined set of data consisted of 54 head impacts, with HIC values ranging from 175 to 3400. HIC durations ranged from 0.9 to 10.1 msec. The lowest HIC value associated with a skull fracture was 450, and the highest HIC value associated with a non-fracture was 2351.

These data were analyzed by Hertz (1993) fitting normal, log normal, and two-parameter Weibull cumulative distributions to the data set, using the Maximum Likelihood method to achieve the best fit for each function. The best fit of the data was achieved with the log normal curve, shown in Figure 2-3. Since the data consists of short duration impacts which were typically less than 12 milliseconds, the HIC curve would be applicable to both HIC_{15} and HIC_{36} . The probability of skull fracture (MAIS ≥ 2) associated with a HIC_{15} limit values of 700 for a mid-sized male is 31 percent. Based on scaling procedures, injury risk levels associated with the proposed HIC_{15} performance limits for each dummy are assumed to be equivalent to the risk for a HIC_{15} value of 700 for a mid-sized adult male.

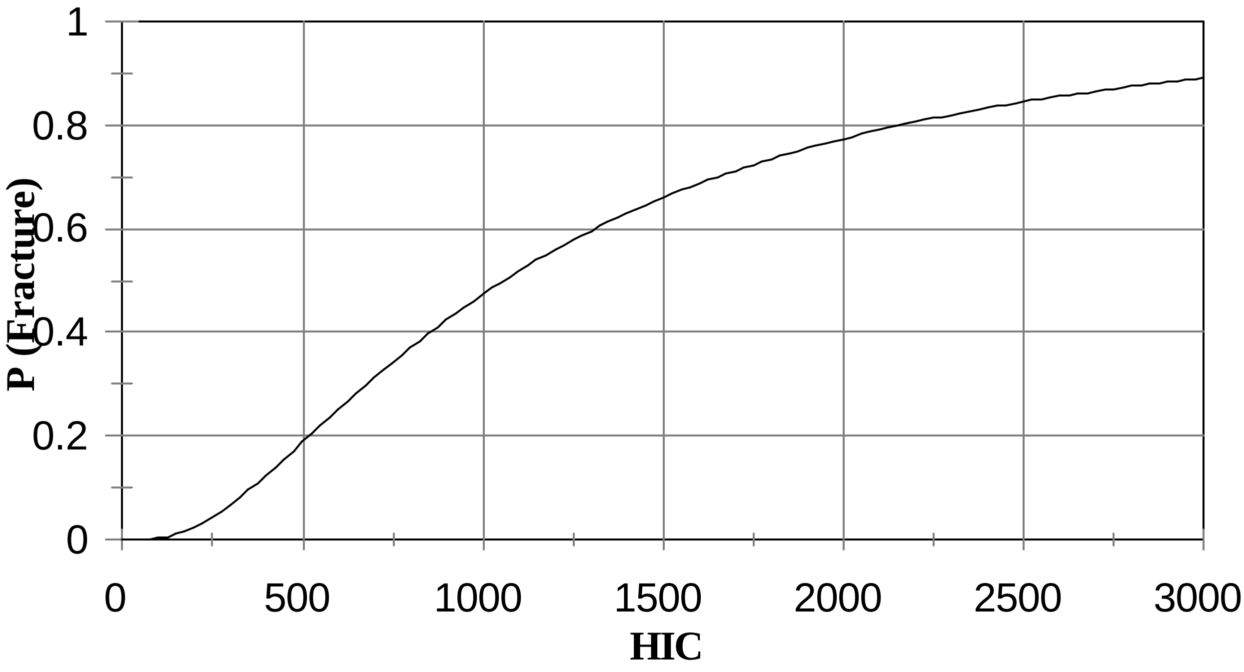

Figure 2-3. Injury risk curve for the Head Injury Criterion (HIC).

The probability of skull fracture (AIS≥2) is given by the formula,

$$p\ (\,fracture) \;=\; N\left(\frac{\ln(HIC) - m}{s}\right)$$

where N( ) is the cumulative normal distribution, $\mu = 6.96352$ and $\sigma = 0.84664$.

2.4 APPLICATION OF HIC TO AVAILABLE TEST DATA

Calculations of HIC_{15} and HIC_{36} were made for a wide variety of test data available in the NHTSA database (Tables B1 thru B25). Analyses were conducted for data from 35 mph NCAP tests, 30 mph FMVSS No. 208 compliance tests, 48 kmph (30 mph) rigid barrier and 40 kmph (25 mph) offset tests with 5th percentile adult female dummies, and out-of-position tests with the 3 year old, 6 year old and 5th percentile adult female dummies. The percentage of vehicles that passed the newly proposed criteria of $HIC_{15} \leq 700$ for the adult dummies and the six year old dummy is discussed below. As expected from initial regression analysis of the NCAP vehicle tests that showed the the two criteria and associated thresholds offer the same stringency for long durations events (Figure 2-2), $HIC_{15} \leq 700$ for the adults shows very similar pass rates as $HIC_{36} \leq 1000$ for all vehicle tests analyzed including those with the 5th percentile female dummy. The equivalency of the two criteria is also demonstrated for direct air bag loading to the head in the out-of-position tests. In these tests, the pass rates of the 5th percentile female and 6 year old child dummy are very simliar for HIC_{15} and HIC_{36}.

Data from a total of 124 NCAP crash tests from 1997 to 1999 model year vehicles were analyzed with ATD's in both the driver and passenger position to determine how the new proposal of $HIC_{15} \leq 700$ would perform if it were adopted. In these tests, about 94% of the drivers and 92% of the passengers had a value of $HIC_{15} \leq 700$.

Data from a total of 40 FMVSS No. 208 compliance tests for 1996-1999 vehicles were analyzed with ATD's in both the driver and passenger positions. All drivers had a value of $HIC_{15} \leq 700$. All passengers in the 1998-1999 model year vehicles had a value of $HIC_{15} \leq 700$. 93% of the passengers in the 1996-1997 model year vehicles had a value of $HIC_{15} \leq 700$. The averages of HIC_{15} for all drivers and passengers are 222 and 239, respectively.

Data from tests conducted at Transport Canada using the Hybrid III 5th percentile adult female dummy in 1998-1999 model year vehicles were also analyzed. In these tests, the 5th percentile female dummies were belted and seated in a fully forward position. For the seventeen 208 tests conducted at 48 kmph, all drivers and passengers had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} equal to 205 and 206, respectively. For the twenty-nine 40% offset frontal tests conducted at 40 kmph, all drivers and all but one passenger had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} equal to 182 and 114, respectively.

Data from four NHTSA 208 tests with unbelted 5th percentile female dummies in 1999 cars were analyzed. All passengers and drivers had a value of $HIC_{15} \leq 700$. The averages for drivers and passengers are 169 and 299, respectively.

The 14 tests with the 5th percentile adult female dummy in the driver position 1 and position 2 using 1998-1999 model vehicles were also analyzed. The position 1 driver test condition with the 5th percentile female dummy is intended to maximize head and neck loading from airbag deployment while the position 2 test condition is intended to maximize chest loading due to air bag deployment. For the position 1 tests, 14 out of 14 tests had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} equal to 79. For the position 2 tests, 14 out of 14 tests had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} equal to 39.

The final set of data analyzed for this report were from Hybrid III 6 year old dummy out-of-position tests using 1996 to 1999 model year vehicles. Out-of-position tests were conducted to investigate the trauma induced when the child dummy is in close proximity to the deploying airbag. Two out-of-position test conditions were considered for the 6 year-old Hybrid III dummy. The child position 1 is designed primarily to evaluate contact forces of the deploying airbag on the head and chest. This position is intended to represent a standardized worst case condition in which the child has been thrown against the frontal structure of the vehicle's interior due to pre-impact braking and/or vehicle impact. The child position 2 is designed to primarily address the contact forces and loading forces of the deploying airbag on the head and neck. This position is intended to represent a worst case scenario in which the child slides forward or is sitting forward on the seat while the upper torso jack-knifes forward toward the instrument panel. 7 out of 7 tests in position 2 using the 1999 model vehicles had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} equal to 246. 15 out of 19 tests in position 1 had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} of 510. 9 out of 12 tests in position 1 with a 4 inch distance from the chest to the instrument panel had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} of 546. 10 out of 11 tests in position 1 with an 8 inch distance from the chest to the instrument panel had a value of $HIC_{15} \leq 700$, with an average value of HIC_{15} of 345.

In summary, almost all the NCAP tests, FMVSS No. 208 compliance tests, Transport Canada offset and rigid barrier tests using the 5th percentile adult female, and out-of-position tests using the 5th percentile adult female passed the proposed injury criteria of $HIC_{15} \leq 700$. However, for out-of-position tests using the 6 year-old, some baseline airbag systems failed the proposed head injury criteria.

Chapter 3
Neck Injury Criteria

3.1 BACKGROUND

The current FMVSS No. 208 alternative sled test includes injury criteria for the neck consisting of individual tolerance limits for compression (compression of the neck), tension (force stretching the neck), shear (force perpendicular to the neck column), flexion moment (forward bending of the neck), and extension moment (rearward bending of the neck). Tolerance values are based on a select number of volunteer, cadaver, and dummy tests. Limits are typically set at minimal threshold levels, but are based on small sample sizes.

The current tolerance level for axial compression was developed by Mertz et al (1978). They used a Hybrid III 50% male dummy to investigate the neck reaction loads when struck by a tackling block that had reportedly produced serious head and neck injuries in football players. The compression tolerance varied with the duration of the load application, with a peak value of 4000 Newtons.

Current tolerance levels for tension and shear loads were developed by Nyquist et al (1980). They used the Hybrid III 50% male dummy to reconstruct real-world collisions, and correlated field injuries with dummy responses for 3-point belted occupants in frontal collisions. Limits for tension and shear were set at 3300 N and 3000 N, respectively.

Tolerance levels for flexion and extension bending moments were based on sled tests conducted on volunteers and cadaver subjects.(Mertz, 1971) Volunteer tests provided data up to the pain threshold, and cadaver tests extended the limits for serious injuries. Ligamentous damage occurred in a small stature cadaver subject at an extension moment of 35 ft-lbs (47.5 Nm). This value was scaled up to an equivalent 50% male level of 42 ft-lbs (57 Nm). No injuries were produced during flexion testing, so the maximum measured value of 140 ft-lbs (190 Nm) was taken as the injury assessment reference value (IARV). It should be noted that these moment tolerance levels are based on human limits, rather than from dummy measurements. Tolerance limits are therefore dependent on the biofidelity of the dummy neck in bending.

Experimental tension tests on cadaveric specimens consist of a small number of studies. Yoganandan et al (1996) tested isolated and intact cadaveric specimens in axial tension under both quasistatic and dynamic conditions. Isolated specimens failed at a mean tension value of 1555 N. Intact specimens failed at a higher mean tension value of 3373 N. Shea et al (1992) investigated the tension tolerance of the neck with a fixed extension angle of 30 degrees. Under this combined loading condition, ligamentous cervical spine specimens failed at a mean tension value of 499 N. These results indicate that the presence of an extension moment would have a significant effect on the tensile tolerance of the cervical spine. One additional test conducted on a live baboon demonstrated that physiological failure of the spinal cord occurs at approximately half the distraction load which causes structural failure of the cervical column (Lenox, 1982).

3.1.1 Adult Versus Child Injury Tolerance

In scaling between people of different sizes and age groups, geometric differences do not fully account for the differences in tolerance to loading. Variations in material properties and the degree of skeletal maturity also have a strong effect on injury tolerance. Real world crash investigations, as documented through NHTSA's Special Crash Investigation Program, show the differences in injury patterns associated with age. For forward-facing children in close proximity to a deploying airbag, typical injuries include atlanto-occipital dislocations with associated contusions or lacerations of the brain stem or spinal cord. Closed head injuries are common, but skull fractures are typically not observed. For adults under the same airbag loading conditions, typical injuries include basilar skull fractures with associated contusions or lacerations of the brain stem or spinal cord. Atlanto-occipital dislocations are typically not observed.(Kleinberger, 1997)

One crude study on pediatric tolerance was conducted in 1874 by an obstetrician who pulled on the legs of stillborn children to determine how much force could be applied in a breech delivery before cervical injury occurred. One additional test was conducted on an infant that had died two weeks after birth. Although based on a single data point, the results indicate that the tolerance of the cervical spine significantly increases even within the first two weeks of life (Duncan, 1874).

Two additional studies were conducted using matched pairs of tests in which a juvenile porcine subject and a 3-year-old child dummy were subjected to out-of-position deployments from a number of different airbag systems (Mertz and Weber, 1982; Prasad and Daniel, 1984). The pig was judged by the authors to be the most appropriate animal surrogate based on a number of anatomical and developmental factors. Measured responses in the child dummy were correlated with injuries sustained by the surrogate. Prasad and Daniel concluded from their results that axial tension loads and extension (rearward) bending moments should be linearly combined to form a composite neck injury indicator. Critical values proposed for tension and extension for the 3-year-old dummy were 2000 N and 34 Nm, respectively.

3.2 DEVELOPMENT OF Nij NECK INJURY CRITERIA

Current FMVSS No. 208 injury criteria for the neck using the alternative sled test include individual tolerance limits for axial loads, shear loads, and bending moments. If axial loads (tension and compression) and bending moments (flexion and extension) are plotted together on a graph, the requirement is that the dummy response must fall within the shaded box, as shown in Figure 3-1.

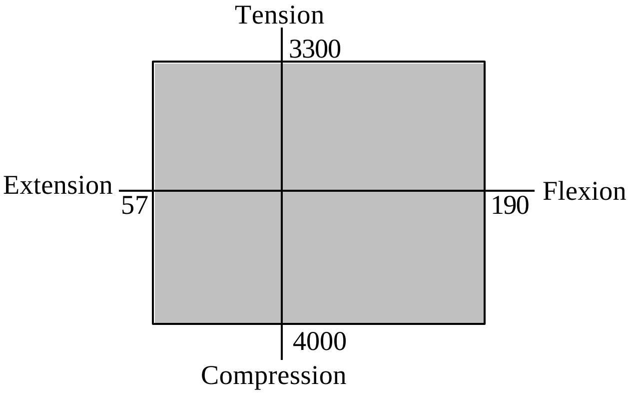

Figure 3-1: Current sled test alternative neck injury criteria.

Using this formulation, if the mid-sized male dummy measures less than 3300 N of tension along with less than 57 Nm of extension moment, it would pass the current criteria. This formulation does not consider the combined effect of extension and tension.

The concept that a composite neck injury indicator based on a linear combination of axial tension loads and extension (rearward) bending moments was developed by Prasad and Daniel (1984) using their results from experimental tests on porcine subjects. Based on their formulation for a 3 year old dummy, the allowable region in the tension/extension quadrant of the plot becomes the shaded area shown in Figure 3-1. Any test falling above the diagonal line in this plot would exceed the tolerance levels.

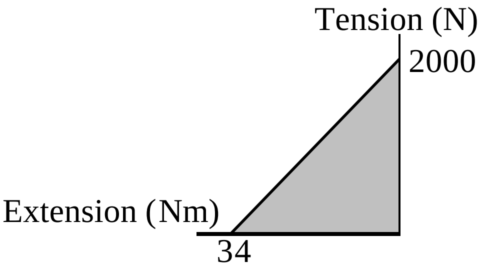

Figure 3-2: Linear combination of axial and tension loads for porcine subjects representing the size of a three year old child (Prasad and Daniel, 1984).

Next, the concept of neck criteria based on a linear combination of loads and moments, as suggested by Prasad and Daniel, was expanded to include the four major classifications of combined neck loading modes; namely tension-extension, tension-flexion, compression-extension, and compression-flexion. Proposed critical intercept values for tension load, compression load, extension moment, and flexion moment were established and are discussed later in section 3-3.

The resulting criteria are referred to as N_{ij}, where "ij" represents indices for the four injury mechanisms; namely N_{TE}, N_{TF}, N_{CE}, and N_{CF}. The first index represents the axial load (tension or compression) and the second index represents the sagittal plane bending moment (flexion or extension). This N_{ij} concept was first presented in NHTSA's report on child injury protection (Klinich, 1996). Graphically, the shaded region of the plot in Figure 3-3 shows the region for all four modes of loading which would pass the performance requirements for Nij. The intercept values shown are those proposed for the Hybrid III mid-sized male dummy.

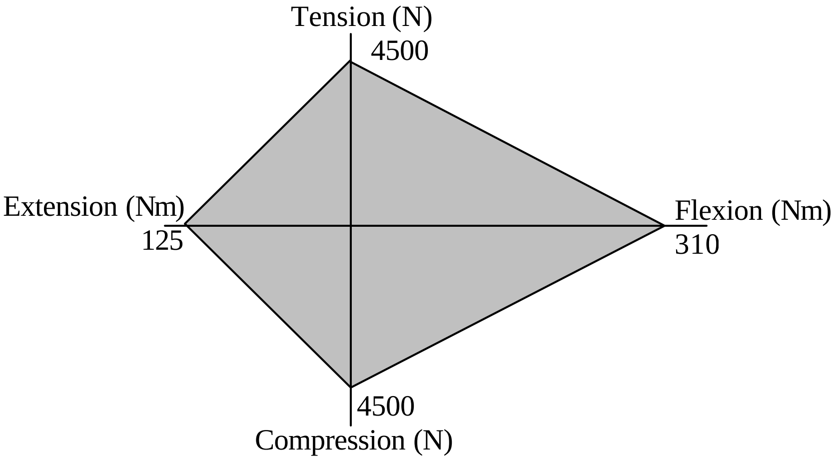

Figure 3-3: SNPRM neck injury criteria for the 50th percentile male dummy.
The shaded region represents combinations of neck forces and moments which would pass the criteria of Nij #1.0.

Since each specific dummy has a unique set of critical intercept values, for subsequent scaling this plot has been normalized by dividing each semi-axis by its critical intercept value for a specific dummy. The resulting plot becomes symmetric about the origin and has maximum allowable values of unity. Graphically, the shaded box shown in Figure 3-4 designates the allowable values of loads and moments represented by this normalized calculation.

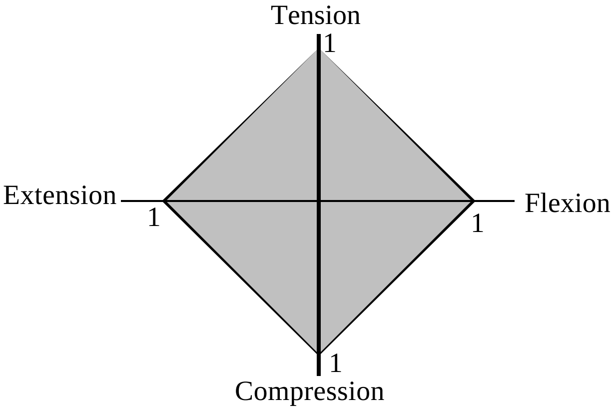

Figure 3-4: Normalized SNPRM neck injury criteria for all dummy sizes.
The shaded region represents combinations of neck forces and moments which would pass the criteria of Nij #1.0.

Real-world cervical injuries resulting from airbag interaction often are classified as tension-extension injuries. A tensile load applied to the neck results in stretching of both the anterior (front) and posterior (rear) soft tissues of the neck. If an extension (rearward) bending moment is superimposed upon the tensile load, the anterior soft tissues will be further stretched while the posterior tissues will become less stretched. Under this loading scenario, a tension-extension injury is more likely to occur than a tension-flexion, compression-extension, or compression-flexion injury. Accordingly, the value for N_{TE} would be expected to be the maximum of the four N_{ij} values.

3.2.1 Method of Calculation of Nij Criteria

In developing the Nij criteria, information produced in crash tests using dummies, and the significance of that information are considered. For any given loading of the dummy, the standard 6-axis upper neck load cell dynamically records the loads and moments in all three directions at the top of the neck. For a frontal collision, primary motion and measured neck reactions occur in the sagittal plane. Out of plane motion and reactions are typically of secondary importance. As a result, only the two measurements associated with sagittal plane motion are used in the current formulation of the N_{ij} neck injury criteria, namely axial load (F_Z) and flexion/extension bending moment at the occipital condyles (M_Y). Shear load (Fx) is only used to calculate the effective moment at the occipital condyles. Using the neck cell polarities established by SAE (SAE J1733, 1994) this is accomplished by multiplying the shear load by the height of the load cell above the condyles and subtracting this value from the Y-axis moment measured by the load cell.

Loads and moments at each instance in time are normalized with respect to the corresponding critical intercept values defined for tension, compression, extension, and flexion. The normalized flexion and extension moments are added to the normalized axial load to account for the superposition of load and moment. The proposed neck injury criteria can thus be written as the sum of the normalized loads and moments.

$$Nij = \frac{F_z}{F_{\text{int}}} + \frac{M_y}{M_{\text{int}}} \tag{3.1}$$

where F_Z is the axial load, F_{int} is the corresponding critical intercept value of load used for normalization, M_Y is the flexion/extension bending moment computed at the occipital condyles, and M_{int} is the corresponding critical intercept value for moment used for normalization. At each instance in time, Fz and My lie in one of the four quadrants shown in Figures 3-3 and 3-4 which correspond to the four loading modes of tension-extension, tension-flexion, compression-flexion, and compression-extension. Nij is computed at each instance in time for only that quadrant where Fz and My lie. For example, if at one instance in time the axial force is +1000 N (*i.e.*, tension) and the bending moment at the occipital condyle is -50 N-m (*i.e.*, extension),

$$N_{TE} = \frac{1000}{4500} + \frac{-50}{-125} = 0.62 \tag{3.2}$$

The maximum Nij in time for each of the four loading modes, represented by the four quadrants in

Figure 3-4, is computed from which the maximum Nij for all the four loading modes is determined.

The values for calculating the N_{ij} are uniquely specified for each dummy, and are defined in Table 3.6 for the CRABI 12-month-old dummy and the Hybrid III 3-year-old, 6-year-old, small female, and mid-sized male dummies. Source code for a C++ program to calculate the Nij criteria using standard test data is included in Appendix G. This source code, as well as an executable version of the program, is also available from the NHTSA web site at http://www.nhtsa.dot.gov.

3.3 DEVELOPMENT AND SCALING OF Nij CRITERIA TO VARIOUS OCCUPANT SIZES

Initial critical intercept values for tension load and extension moment were calculated for the 3 year old dummy based on the Mertz/Prasad experimental test data. As noted at the beginning of section 3.2, previously published tolerance levels were based on individual tolerance limits. These independent limits, which do not account for the complex combined loading, were published in context of the short-term alternative sled test. Critical intercept values for axial load and sagittal plane bending were previously determined by assuming that each measurement was independently linked to the resulting injury. Tension limits were set assuming that no extension moment was applied. Similarly, bending limits were set assuming that no tension was present.

In the previous report (NHTSA Docket 98-4405-9), engineering judgement of the tolerences of the adult human neck was used to determine the weighting of the relative importance of the tension and extension in the Nij formulation, which is hereafter referred to the NPRM Nij. Then, the Mertz/Prasad paired pig and dummy data were re-analyzed using a multi-variate logistic regression to determine the predictive ability for the combination of tension and extension in the NPRM Nij formulation. The resulting critical values in the NPRM Nij formulation were 2500 N for tension and 30 N-m for extension for the three-year old. In their response to the NPRM, the AAMA suggested a slightly different linear combination of the axial forces and bending moments in the neck to predict the failure of the anterior-longitudinal ligament (ALL). This combination assumed that the force in the ALL would be equal to one-half the measured tensile force and that the additional tensile force due to extension would be equal to the measured extension moment divided by the distance from the anterior surface of the atlas to the posterior surface of the ALL. Based on these assumptions, the resulting critical values for the three-year old are 2120 N for tension and 26.8 N-m for extension. In light of the large biomechanical variability in humans, the proposal by NHTSA and the AAMA for the critical values are essentially the same and NHTSA has adopted the AAMA limits for the three-year old as the basis for the formulation of the Nij which is used in the SNPRM. However, it is important to note, that due to different statistical techniques used by the AAMA and the agency which are discussed in detail in Chapter 1, the probability of AIS 2+ risk associated with a value of SNPRM Nij = 1.0 is 5% according to the AAMA's techniques and 22% according to the agency's techniques.

Critical intercept tension and extension values for other dummy sizes were scaled from the 3 year old dummy using the scaling techniques presented in Chapter 1 and include the effect of age dependent failure stress. The AAMA proposed using the failure stress of the calcaneal tendon for the determining the failure stress ratio. Forces were scaled according to cross-sectional area of the neck, represented by the circumference squared, multiplied by the failure stress of the ligaments ($8F_f\ 8_L^2$). Bending moments were scaled according to the third power of the characteristic neck length, represented by the circumference cubed, multiplied by the failure stress of the ligaments ($8F_f\ 8_L^3$). Circumference measurements are used to quantify characteristic neck length because it is a simple measurement to record. Circumference measurements, failure strength of the calcaneus tendon, and the associated scale factors for each dummy size are shown in Table 3.1. Values included in this table were selected from several anthropometric studies conducted on adults and children (Snyder 1977, Schneider 1983, and

Weber 1985).

Table 3.1. Comparison of Scale Factors for Various Dummy Sizes.

Dummy	Neck Circumference (mm)	Neck Length Scale Factor 8_L	Failure Strength F_f (kg/mm^2)	Failure Stress Scale Factor $8F_f$
CRABI 12-month-old	224	0.585	3.91	0.70
Hybrid III 3-year-old	244	0.637	4.76	0.85
Hybrid III 6-year-old	264	0.689	5.39	0.96
Hybrid III small female	304	0.794	5.6	1.00
Hybrid III mid-sized male	383	1.000	5.6	1.00
Hybrid III large male	421	1.099	5.6	1.00

Table 3.2. Comparison of Axial Scaling Factors for Various Dummy Sizes.

Dummy	Axial Force Scale Factor $8F_f\ 8_L^2$	Axial Force Scale Factor (MCW)
CRABI 12-month-old	0.240	0.26
Hybrid III 3-year-old	0.345	0.29
Hybrid III 6-year-old	0.456	0.35
Hybrid III small female	0.630	0.63
Hybrid III mid-sized male	1.000	1.00

Table 3.3. Comparison of Extension Scaling Factors for Various Dummy Sizes.

Dummy	Extension Scale Factor $8F_f\ 8_L^3$	Extension Scale Factor (MCW)
CRABI 12-month-old	0.140	0.22
Hybrid III 3-year-old	0.220	0.32
Hybrid III 6-year-old	0.314	0.41
Hybrid III small female	0.501	0.70
Hybrid III mid-sized male	1.000	1.00

Kumaresan et. al (Appendix F) used an alternative scaling technique to determine the critical force and moment values based on a literature survey of age dependent failure strengths of the various ligaments in the neck. This alternative technique shows similar scaling factors as those based on the calcaneal tendon failure strength (Tables 3.2 and 3.3).

Applying the scale factors from Table 3.1 to the critical intercept tension and extension limits for the 3 year old dummy yields the critical intercept values for all dummy sizes shown in Table 3.4. Values for critical intercept compression and flexion were established by setting fixed ratios between tension and compression loads, and between extension and flexion moments.

Table 3.4. Scaled Critical Intercept Values for Tension and Extension.

Dummy	Tension (N)	Extension (Nm)
CRABI 12-month-old	1465	17
Hybrid III 3-year-old	2120	27
Hybrid III 6-year-old	2800	39
Hybrid III small female	3880*	62
Hybrid III mid-sized male	6170*	125

* Proposed axial load limits for adult dummies are based on experimental data and are lower than the scaled values presented in this table.

To better understand the relationship between dummy and human responses to loading, a modeling study was conducted using MADYMO to determine a scale factor between human and dummy neck loads and moments (Nightingale, 1998). In addition to the standard MADYMO model of the Hybrid III dummy provided with the software, a second model was created to represent a human occupant. Axial stiffness of the neck and rotational stiffness of the occipital condyle joint were modified individually and in combination to determine their effect on measured loads. A generic airbag model was deployed into an out-of-position driver model initially placed in an ISO 1 position, which is intended to maximize loading on the head and neck. A summary of the results is presented in Table 3.5. These results indicate that the measured extension moments for the 50th percentile male dummy were approximately 2.4 times higher than for a human, whereas the tension and shear measurements did not change dramatically. This supports the recommended critical intercept extension moment value of 125 Nm suggested above for the mid-sized male dummy, although it is slightly more than double the previous human-based value of 57 Nm (Mertz, 1971).

Table 3.5. Neck Reactions from Simulations of OOPAirbag Deployments.

Model Configuration	Tension (N)	Shear (N)	Extension Moment (Nm)
Hybrid III Axial Stiffness Hybrid III Rotational Stiffness (Full Hybrid III Dummy Model)	4744	2787	-173*
Human Axial Stiffness Hybrid III Rotational Stiffness	3503	2653	-152
Hybrid III Axial Stiffness Human Rotational Stiffness	4599	4105	-123
Human Axial Stiffness Human Rotational Stiffness (Full Human Model)	3717	2769	-72*

* A ratio of approximately 2.4 exists between the Hybrid III and human extension moment responses.

Critical intercept values for flexion moment were set by maintaining a ratio of 2.5 between flexion and extension. This is the same as the ratio proposed by the AAMA for out-of-position evaluation of air bags in which the flexion limit for the 50th percentile male is 190 N-m and the extension limit is 77 N-m. Moment limits previously stated in the literature were based on human cadaveric tolerances, and did not represent dummy-based values (Mertz, 1971). Moment tolerances used in this report are based on dummy responses, and are significantly higher than the values in the regulations for the alternative sled test. Proposed SNPRM critical intercept values for extension and flexion moment for all dummy sizes are shown in Table 3.6.

Table 3.6. Proposed Critical Intercept Values for SNPRM Nij Neck Injury Calculation.

Dummy	Tension (N)	Compression (N)	Flexion (Nm)	Extension (Nm)
CRABI 12-month-old	1465	1465	43	17
Hybrid III 3-year-old	2120	2120	68	27
Hybrid III 6-year-old	2800	2800	93	39
Hybrid III small female	3370	3370	155	62
Hybrid III mid-sized male	4500	4500	310	125
Hybrid III large male	5440	5440	415	166

Axial loading of the adult neck is a test condition for which there is significant experimental data. Proposed critical intercept values of tension and compression for adult dummies are therefore based on experimental data rather than on scaling. Pintar and Yoganandan (Pintar et al., 1998) conducted dynamic compression tests to the head/neck complex with impact velocities ranging from 0.25 cm/s to 800 cm/s. Measured loads and accelerations on the specimens were correlated with documented injuries sustained by the specimens. The natural lordosis in the cervical spine was removed by forcing it to be in a straight column which approximates a pure axial compressive load to the cervical spine. The compressive tolerance level of the cadaveric specimens varied from 7 kN for the young to 2 kN for the very old. Based on regression analysis of the data, a compressive tolerance level of about 4500 N under dynamic loading conditions was estimated for males in the age range of 30-35 years. Using a drop track system, Nightingale et al. (1997) conducted similar dynamic compression tests on 22 cadaveric head/neck specimens in which the natural lordosis of the cervical spine was maintained. Thus, the specimen had a combination of axial load and moment which contributes to failure. The mean compressive force to failure in the Nightingale et al. study was signficantly lower than that in the Pintar et al. study for male specimens of similar mean age. The lower injury tolerance in the Nightingale study is due to the additional bending moment present, which is minimized in the Pintar study by removing the lordosis. This is consistent with the biomechanical basis of Nij. The axial failure force in these two studies is in about the same range as the previously published injury assessment reference values of 3300 N for tension (Nyquist 1980) and 4000 N for compression (Mertz 1978).

Based on the experimental data discussed above with axial tolerances of the human neck of ranging from 3300 to 4500 N depending on test conditions, the scaled values of 3880 and 6170 N for the small female and mid-sized male appear to be too high. This discrepancy can be expected due to the large size differences and structural differences between the neck of an adult and the neck of the three year old subject from which the Nij formulation was derived. Thus, based on the experimental data of Pintar (1995) which most closely represents a pure axial compression of the cervical spine, an axial limit for the mid-sized male dummy of 4500 N is proposed. The axial limit proposed for the small female is 3370 N, which is based on the interpolating the tension value for the 6 year old and the mid-sized male according to the scaling ratios presented in Table 3.1. Preliminary NHTSA-sponsored tests on cadaveric head/neck specimens indicate that the tolerance of the neck to compression is not significantly different from the tolerance for tension (Nightingale, unpublished). As a result, the axial load limit in tension is assumed to be equal to that in compression. The axial limits for the adult dummies are slightly higher than those proposed in the NPRM and are consistent with the option in the NPRM to allow a performance limit of Nij up to a value of 1.4. Based on the agency’s analysis of comments by many groups to adopt conservative values of neck injury criteria, especially for children, the Nij critical values presented in Table 3.6 for the child dummies are lower than those proposed in the NPRM. This conservativeness is warranted until sufficient data is available to support higher tolerances for the pediatric neck.

3.4 NECK INJURY RISK ANALYSIS

Risk curves previously presented by Mertz (1997) were calculated based on the Mertz/Weber modified Median Rank method using experimental data from porcine subjects.(Mertz, 1982; Prasad, 1984) These data using the linear combination of forces and moments suggested by Mertz as described in the section 3.3 were re-analyzed using logistic regression, yielding the porcine risk curve shown in Figure 3-5. This curve represents the probability of injury to a porcine subject as a function of the measured loads and moments on a 3 year old child dummy placed in the same conditions, such as in close proximity to a deploying airbag. An Nij value of 1.0 on this curve is associated with approximately a 22% risk of an AIS≥3 injury.

In order to establish the corresponding risk curve for a live human subject, a comparison was made between the injury rates predicted using Nij calculations from experimental dummy test data and real world injury rates estimated from the National Automotive Sampling System (NASS) database. Data from 1997, 1998, and 1999 New Car Assessment Program (NCAP) crash tests were analyzed and compared with NASS cases from similar crash conditions. NCAP tests involve a 56 kmph (35 mph) full rigid barrier impact with belted mid-sized male dummies in both the driver and passenger seating positions. It is important to note that NCAP tests use a 56 kmph (35 mph) impact velocity and belted dummies, whereas FMVSS No. 208 compliance tests at 48 kmph (30mph) use both belted and unbelted dummies. Therefore, it is not a requirement that NCAP tests meet FMVSS No. 208 injury criteria.

The probability of neck injury, given that a crash occurred, was examined for real world non-rollover frontal crashes in various delta-V ranges. Neck injuries included vertebral fractures, contusions, lacerations, and transections of the cord, as well as brain stem injuries and basilar skull fractures that occur as a result of loading to the neck. Although the biomechanical tolerance curves were based on AIS≥3 neck injuries, AIS≥2 NASS data was examined because there are a number of fatal injuries coded as AIS 2 "broken neck, only information available." Generally, these injuries represent only about 1-3% of all AIS 2+ cases, and in the case of airbag vehicles there was only one AIS 2 case in the data between 25 and 30 mph delta V, which is not considered in the final analysis when only higher delta V crashes are considered.

Results from this risk comparison indicate that for New Car Assessment Program (NCAP) crash conditions, NASS data show about a 3 to 7 percent probability of neck injury for belted occupants of airbag equipped vehicles compared to about a 12 percent probability of neck injury predicted using the Nij critical values listed in Table 3-4. For unbelted occupants with air bags, the probability of neck injury estimated from NASS is about 1 to 7 percent compared to about a 9 percent probability of neck injury from unbelted crash tests at 30 mph.

In the previous report which used the NPRM critical values, an adjustment was made to the original porcine risk curve to establish a human curve to account for differences between estimates of neck injury rates based on NASS and experimental test data. By contrast, using the critical values developed in this document, an adjustment to the original porcine risk curve was not necessary because the NASS estimates were reasonably close to the experimental estimates of neck injury rates. Since the Nij criteria are defined as normalized injury measures, an Nij value of 1.0 represents a 22% risk of AIS 3+ injury for all occupant sizes. The original porcine data from Mertz (1982) and Prasad (1984) were also used to calculate a risk curve for AIS$2, 4, and 5 injuries using logistic regression and are presented in Equation 3.2.

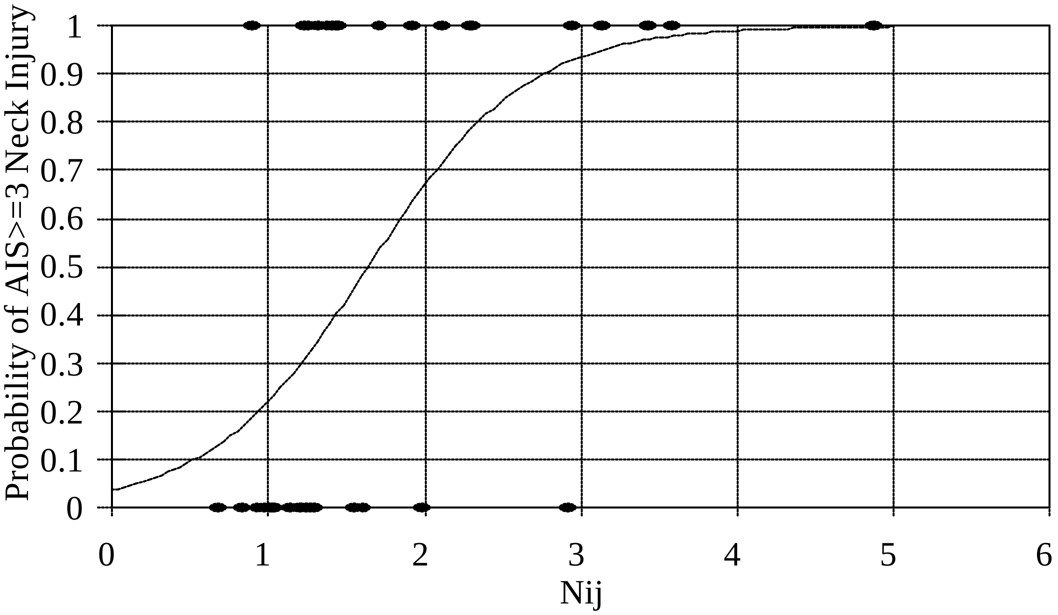

Figure 3-5. Injury Risk Curve for N_{ij} Neck Injury Criteria.

$$
\begin{aligned}
p(AIS \geq 2) &= \frac{1}{1 + e^{2.054-1.195Nij}} \\
p(AIS \geq 3) &= \frac{1}{1 + e^{3.227-1.969\,Nij}} \\
p(AIS \geq 4) &= \frac{1}{1 + e^{2.693-1.195Nij}} \\
p(AIS \geq 5) &= \frac{1}{1 + e^{3.817-1.195\,Nij}}
\end{aligned}
\tag{3.2}
$$

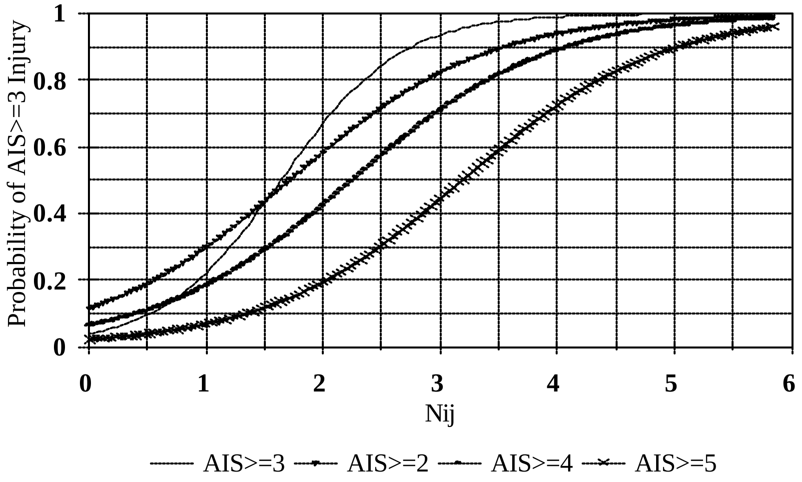

Figure 3-6. N_{ij} Risk Curves for AIS 2+ to AIS 5+ Injuries.

3.5 APPLICATION OF PROPOSED Nij CRITERIA TO AVAILABLE TEST DATA

Calculations of Nij were made for a wide variety of test data available in the NHTSA database. Analyses were conducted for data from NCAP tests for both drivers and passengers, FMVSS 208 30 mph rigid barrier crash tests with 1998 vehicles, 25 mph offset tests with 5th percentile female drivers and passengers, 30 mph rigid barrier tests with 5th percentile female drivers, and out-of-position tests for 6 year old and 5th percentile female dummies. Results from these tests are presented graphically in Appendix A, and are included in tabular format in Appendix C.

Comparisons between the Nij combined neck injury criteria and the suggested performance limits submitted by the AAMA for out-of-position occupants are shown for the different types of data analyzed. Two points are plotted for each test, corresponding to each set of injury criteria. A typical plot is shown in Figure 3-7.

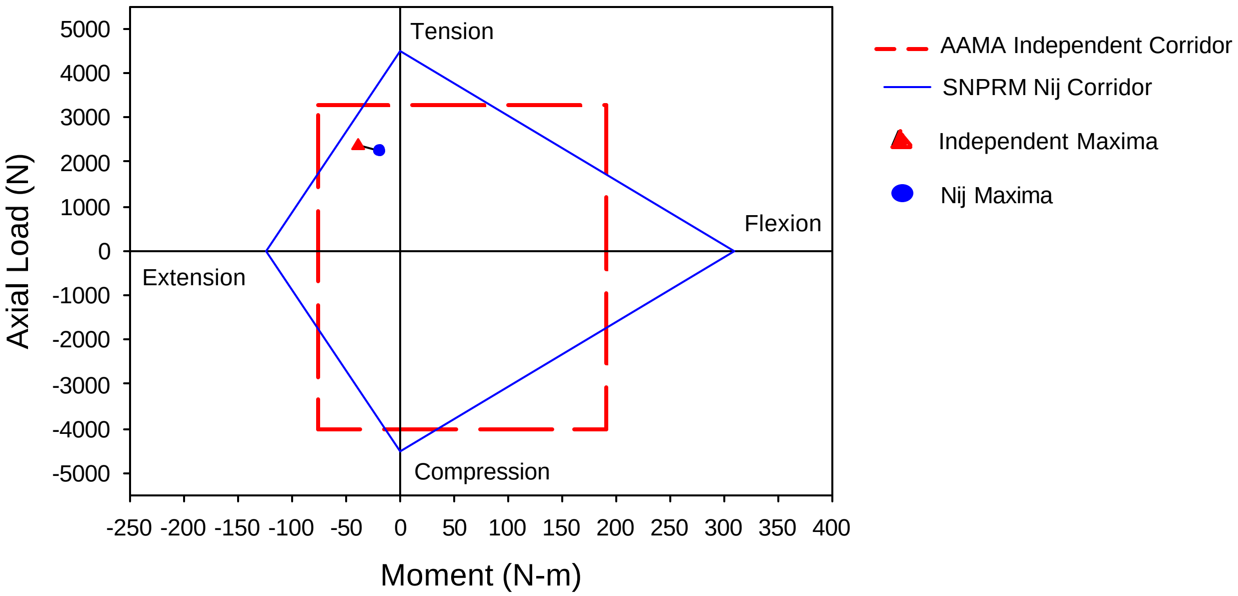

Figure 3-7. Typical Plot Comparing Nij with Current Injury Criteria.

The point corresponding to the Nij criteria, labeled with a **Ž**, is located at the values of axial load (F_Z) and flexion/extension bending moment (M_Y) which yield the maximum value for Nij. It is important to realize that these values for F_Z and M_Y are concurrent in time and are not necessarily equal to the maxima during the entire event. The point corresponding to the AAMA proposed values for out-of-position, labeled with a •, is located at the overall maximum values of axial load and bending moment. The two values that determine this point are independent of time, and do not necessarily occur at the same time. It is also important to notice that shear load is not included on this plot.

Since the AAMA independent point always represents the overall maxima while the Nij point does not, it is impossible for the Nij point to be located further from the origin than the 208 point. To help identify the matched sets of points, they have been joined together by a line. If the line segment is short, and the points lie essentially on top of one another, it implies that the Nij maximum value occurs close to the same time as the independent maxima. If the line segment is long, this indicates that the Nij maximum occurs at a much different time than the independent maxima.

The thick broken rectangle in Figure 3-3 represents the AAMA proposal for neck injury criteria for axial load and bending moment in out-of-position testing. The AAMA's suggested independent limits for tension, compression, flexion and extension which are the same as those used currently for the 50th percentile male in the alternative sled test option, with the exception of the extension value. The AAMA's proposed a limit in extension for the 50th percentile male is 77 N-m for out-of-position testing and 96 N-m for in-position testing, which are higher than the 57 N-m used currently for the sled test. The AAMA reasoned that for in-position testing because the occupant would be aware of the crash and would tense the neck muscles, the performance limits could be raised for tension and extension.

However, the agency has determined that it is not prudent to raise these limits because not all occupants, especially passengers, may be aware of an impending crash and furthermore because there was little scientific data to support the large increase in the extension tolerance to 96 N-m. Thus, the limit of 77 N-m is plotted for the extension limit for the 50th percentile male. The solid "kite" shape represents the Nij = 1.0 criteria, corresponding to a 22% risk of an AIS$3 injury. The vertices for each region shown on the plot are scaled for each different dummy size. Data points lying within either the box or kite are considered to pass the corresponding criteria.

3.5.1 Vehicle Crash Testing with the 50th Percentile Male Dummy

NCAP data from 1996 through1999 were analyzed for both drivers and passengers. A total of 307 occupants from 154 tests conducted from 1996 to 1999 were analyzed. Results are summarized in Figures 3-8 and 3-9 and also in Appendix Figures C.1 through C.4. In each year, more than 90% of the occupants in the driver or passenger position passed SNPRM Nij performance limit of 1.0, with a maximum value 1.42 for the driver in a model year 1996 vehicle with an airbag and a maximum value of 1.55 for one passenger in a model year 1996 vehicle with an airbag.

Limited crash test data are available for the analysis of neck injury risk in unbelted frontal collisions because neck load cells were not required in compliance tests prior to the 1997 adoption of criteria in the sled test alternative under FMVSS 208. A series of thirteen tests conducted under FMVSS 208 barrier crash conditions with 1998 and 1999 vehicles was conducted by the agency using the 50th percentile male dummy. Results from these tests are shown in Figure 3-9 and in Appendix Figures C.5 and C.6. All thirteen tests, both drivers and passengers, easily fall within the allowable range for the SNPRM Nij criteria.

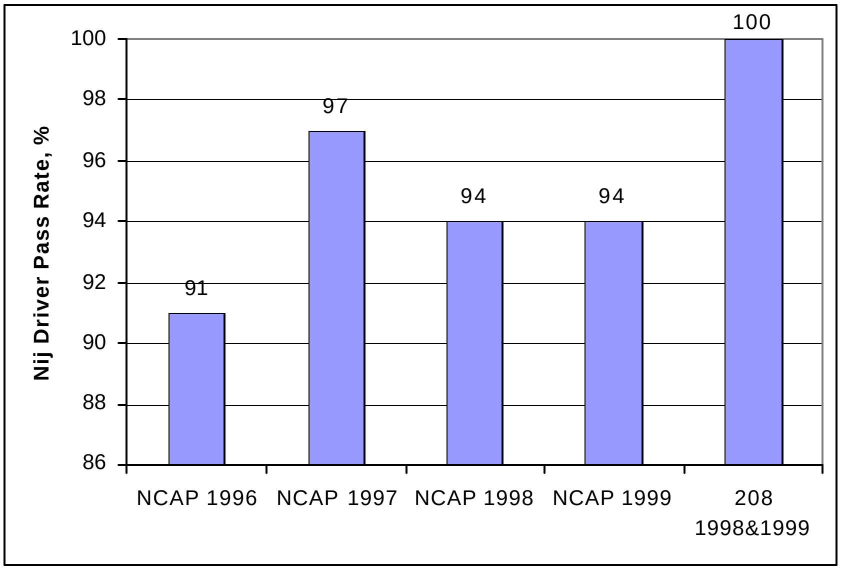

Figure 3-8: SNPRM Nij Pass Rates for the 50th percentile male dummy in the driver position
Belted NCAP at 35 mph into flat, rigid barrier, and unbelted 208 tests at 30 mph into flat, rigid barrier.

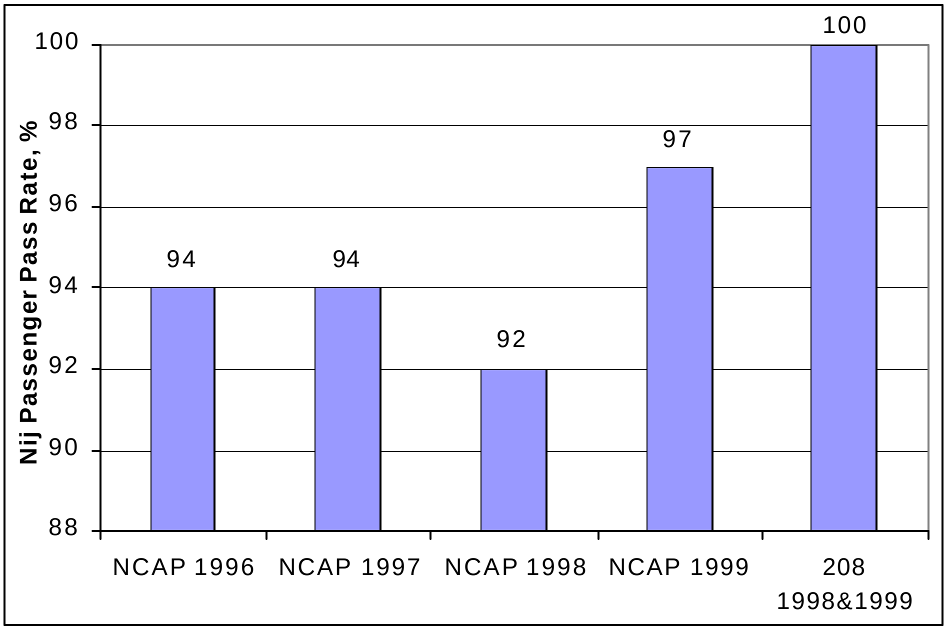

Figure 3-9: SNPRM Nij Pass Rates for the 50th percentile male dummy in the passenger position Belted NCAP at 35 mph into flat, rigid barrier, and unbelted 208 tests at 30 mph into flat, rigid barrier.

3.5.2 Vehicle Crash Testing with the 5th Percentile Female Dummy

Data from recent tests conducted at Transport Canada using belted Hybrid III 5th percentile female dummy in model year 1998 and 1999 vehicles were also analyzed. In these tests, the 5th percentile female dummies were belted with the seat positioned as far forward as possible and the seatback adjusted slightly more upright. Due to the far forward seating position and potential for late deployments for the offset tests, these conditions are quite severe and are somewhat similar to dynamic out-of-position tests.

Results from 48 kph (30 mph) rigid barrier tests and low speed tests into an offset deformable barrier are presented in Figures 3-10and 3-11and in Appendix Figures C.7 thru C.10. For the twenty-six rigid barrier tests which were conducted, 65% of the drivers and 92% of the passengers passed the Nij performance limit of 1.0. For the twenty-nine 40 percent offset frontal tests conducted at speeds varying from 20 to 25 mph in which the air bag deployed, 66% of drivers and 90% of passengers passed the Nij = 1.0 criteria. In some of the lower speed offset tests, the air bag did not deploy and are indicated in Appendix Tables B.15 and B.16 with an asterisk.

These results using current air bag system demonstrate that testing with the belted 5th percentile female in the full forward position at speeds up to 30 mph in a rigid barrier or up to 25 mph into an offset deformable barrier is a practicable test which is being met by over 50% of the vehicles. Similar testing of the unbelted 5th percentile female dummy in a 30 mph rigid barrier test showed similar performance with 3 out of 4 vehicles passing on the driver and passenger side (Appendix Figures C.11 and C.12). However, this testing indicates that some vehicles will need to be redesigned to ensure safety for all occupant sizes at all available seating positions in the vehicles.

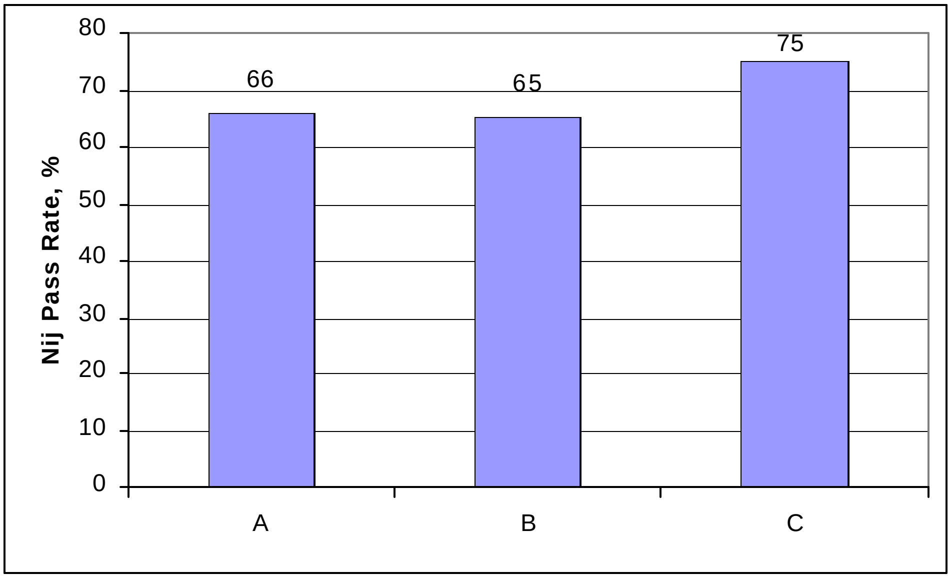

Figure 3-10:Nij Pass Rates for the 5th percentile female dummy in the driver position
A - belted tests at 25 mph into an offset deformable barrier, B - belted tests at 30 mph into flat, rigid barrier, and C - unbelted 208 tests at 30 mph into flat, rigid barrier

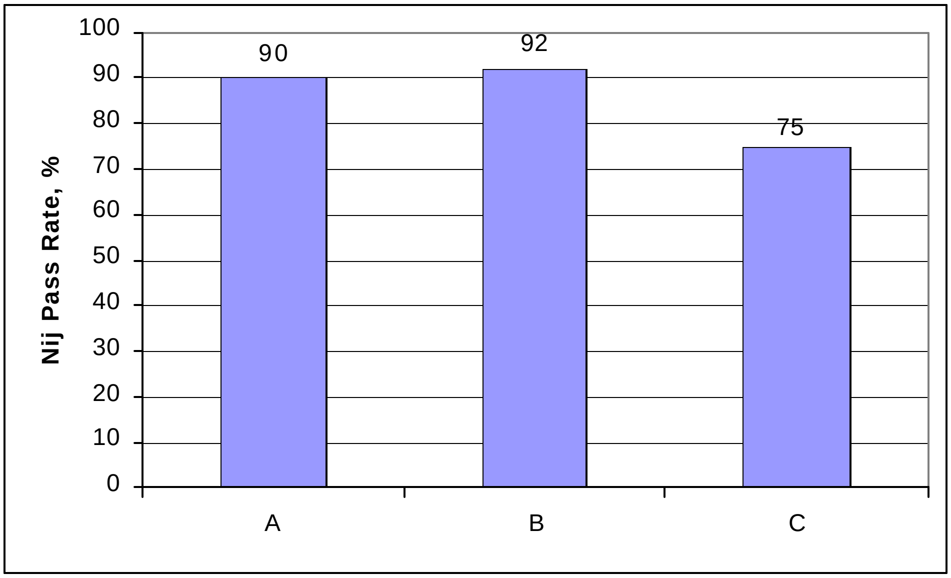

Figure 3-11 Nij Pass Rates for the 5th percentile female dummy in the passenger position
A - belted tests at 25 mph into an offset deformable barrier, B - belted tests at 30 mph into flat, rigid barrier, and C - unbelted 208 tests at 30 mph into flat, rigid barrier

3.5.3 Out-of-position Testing with the 5th Percentile Female Dummy and Child Dummies

Out-of-position tests for different sized dummies were also conducted and analyzed by NHTSA. Driver position 1 for adult dummies places the chin just above the airbag module; position 2 centers the sternum on the module. Driver position 1 tests for adults are intended to maximize loading to the head and neck, resulting in higher risk of neck injuries. For children, the position 2 places the chin above the airbag module. Thus, position 2 tests for children are intended to maximize loading to the head and neck, resulting in higher risk of neck injuries. Since these tests represent the worst case scenarios involving airbag deployments, dummy measurements are expected to be relatively high.

Results from the 5th percentile female tests using 1996, 1998 and 1999 model year air bag systems are shown in Figure 3-12 and in Appendix Figures C.13 and C.14. For the 5th percentile female dummy, 5 of 15 tests (33%) in position 1 and 10 of 15 tests (67%) in the position 2 passed the Nij performance limit.

Figure 3-12: Nij Pass Rates for the 5th percentile female dummy in driver position 1 and position 2

Out-of-position data for the six year-old dummy in position 1 and position 2 were also conducted. In addition, to quantify the effect of proximity of the dummy to the air bag module on neck injury, a series of tests in modified position1 in which the dummy is placed 4 and 8 inches away from the air bag were conducted on 1998 model year air bag systems. For the position 1 tests using 1996, 1998 and 1999 model year air bag systems, 2 of 18 tests (11%) passed the Nij criteria of 1.0. For the position 2 tests using a series of air bags from 1999 model year vehicles, 2 of 7 tests (29%) passed (Figure 3-13). The 1999 Acura RL, which has dual-stage passenger air bag, was tested in position 1 and position 2 positions in two ways: (1) firing only the first stage and (2) firing the both stages with a 40 ms delay between the two stages. For the first stage only firing, the Nij values were 0.91 and 0.83 for positions 1 and 2, respectively. For the two stage firing with delay, the Nij values were 1.26 and 0.94 for positions 1 and 2, respectively. Thus, the first stage Acura RL was the only air bag system which passed Nij for both positions.

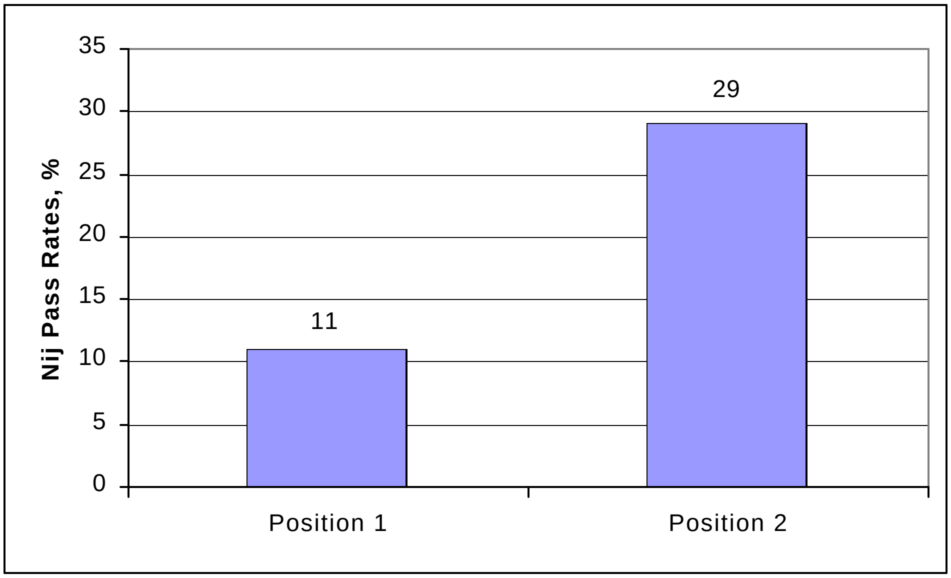

Figure 3-13: Nij Pass Rates for the 6 year-old dummy in child positions 1 and 2

3.5.4 Vehicle Crash Reconstruction Testing

The final set of test data analyzed for this report was from a series of crash reconstructions conducted with a Hybrid III 6-year-old dummy. Three cases involving serious and fatal injuries to a child of approximately 6 years of age were selected from reports prepared by NHTSA's Special Crash Investigation Team. An additional two cases involving only minor injuries were selected from NASS. The three cases involving serious and fatal injuries fail Nij by a wide margin, as demonstrated by their location well outside of the allowable kite shape (Figure 3-14). The two cases involving only minor injuries pass Nij and are within the allowable kite shape.

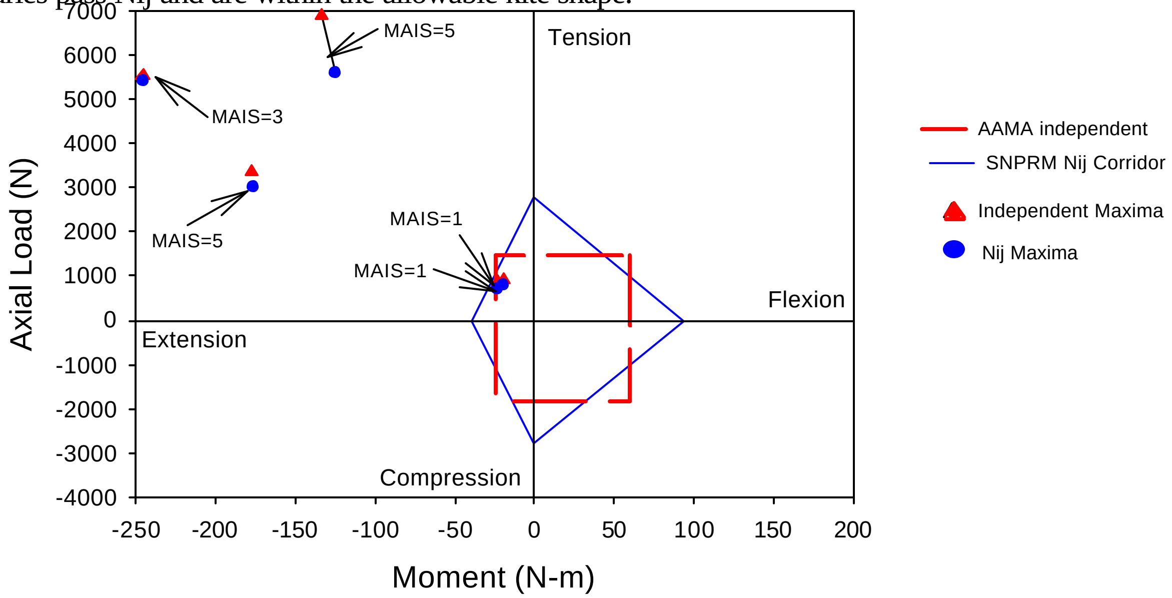

Figure 3-14: Nij for Crash Reconstruction using the 6 year-old dummy

3.5.5 Comparison of Nij with Independent Evalution of Neck Forces and Moments

The AAMA supported the independent evaluation of neck forces and moments, rather than the evaluation of combined loads used by Nij. Thus, the AAMA proposed separate performance limits for tension, compression, flexion, and extension. The pass rates for the various data sets described above using the AAMA independent method are also presented in Appendix C. Overall, the proposed neck injury criteria, Nij, and the independent performance limits show very similar pass rates for all dummy sizes. Moreover, if a vehicle fails Nij it typically fails at least one of the independent performance limits and vice versa. Since the two criteria appear to be equally stringent and the agency believes that the superposition of forces and moments has a better biomechanical basis, Nij will remain as the proposal for the SNPRM.

3.5.6 Issues

There have been crash test situations where the agency has observed high neck moments being generated at the upper load cell of the Hybrid III dummy within 20 milliseconds of the initiation of large neck shear loads without observing substantial angular deformation of the dummy neck. While we believe that these are true loads being generated by the restraint system and not artifacts of an inappropriately designed neck transducer, we are uncertain whether this loading condition is biomechanically realistic. That is, the current Hybrid III neck exhibits considerable bending resistance (i.e., inflexibility) at its occipital condyle joint. The inflexibility may allow large moments to be transmitted to the neck by the head without much relative motion. This, in turn, can create a situation in which the angular deflection due to the applied moment is opposed and even sometimes nullified by the superimposed angular deflection induced by the neck's shear force. Thus, high moments can be produced with little observable rotational deformation of the neck. In contrast to this, the human occipital condyle joint appears to have considerable laxity which requires it to experience significant rotation (± 20 degrees of the head with respect to C1) before it can sustain a substantial moment across it. This would suggest that rapid, high moments generated on a dummy without any concomitant head/neck rotation are possibly an artifact of Hybrid III's neck design and not necessarily a real load that contribute to the potential for neck injury.

We seek comment on whether anyone else using the Hybrid III dummy has experienced this rapidly produced high moment/low angular deflection condition, whether they agree or disagree with our analysis of the mechanics and possible consequences of the situation, and whether they have any biomechanical data supporting either maintaining the current neck design or justifying its modification.

We note that it would not be possible to modify in any significant way the current neck design within the time frame of this rulemaking, i.e., before the March 1, 2000 deadline for a final rule. Moreover, we believe that dummies with the current neck are adequate for measuring risk of neck injury in the proposed tests. To the extent that commenters advocate modifying the neck, we ask them to address how dummies with the current neck should be used in the final rule to measure risk of neck injury.

There is another technical issue related to the Hybrid III dummy neck for which we are seeking public comment. On the selection of data channel, SAE J 211, paragraph 5, states "that selection of frequency response class is dependent upon many considerations, some of which may be unique to a particular test." Further, SAE J211 notes that "(t)he channel class recommendations for a particular application should not be considered to imply that all the frequencies passed by that channel are significant for the application." In the case of head-to-air bag interaction, the agency observed that the specified channel frequency class (CFC) for the neck at 1,000 for force and 600 for the bending moment admits neck data that has spikes of very short duration that may not be appropriate for evaluating the potential for neck injury to the human. Preliminary evidence indicates that the human neck response under similar impact would respond with considerably lower frequency response class data, which implies that the neck response data when processed for injury assessment should be filtered to a lower CFC level than suggested by SAE J211. Accordingly, the agency seeks comments on an appropriate CFC for evaluating data from neck load cells for injury assessment purposes and whether that CFC should depend on the impact environment (e.g., vehicle crash tests, out-of-position tests, etc.)

3.6 RECOMMENDATIONS

Taking into consideration all of the experimental data for the various crash test conditions presented in this section, and comparing the results with real world injury statistics, the recommended neck injury criteria reasonably predict the occurrence of injuries in these types of crashes. Based upon the foregoing analysis, the Nij criteria have been demonstrated to be a reasonable injury criteria for use with the proposed upgrade to the FMVSS 208 frontal impact protection standard.

Chapter 4
Thoracic Injury Criteria

4.1 BACKGROUND

Classic work by Stapp (1970) and Mertz and Gadd (1968) led to the development of the injury threshold for chest acceleration of 60G's. The first injury assessment recommendation for the rib cage and underlying organs using chest deflection was developed by Neathery et al. (1975) for blunt frontal loading. Neathery et al. recommended a chest injury assessment value of three inches maximum sternal compression for a 50th percentile male in blunt frontal impact. This recommendation represented a 50% risk of an AIS $3 thoracic injury for a 45 year old human.

Viano and Lau (1988) re-analyzed the data Neathery used and provided a recommendation of 35% external chest compression to avoid rib cage collapse due to multiple rib fractures and crush to internal organs. Assuming a chest depth of 229 mm for the 50th percentile male, this corresponds to a chest deflection of 65 mm. Based on this study, Mertz (1984) revised his original maximum chest deflection requirement from 75 mm to 65 mm for blunt impact.

Mertz et al. (1991) developed thoracic injury risk curves based on Hybrid III chest compression response with shoulder belt loading by comparing the chest compression response of the Hybrid III dummy with injuries to car occupants in similar exposures. According to Mertz's injury risk curve for belt restrained occupants, 2 inches of chest compression in the Hybrid III dummy is associated with a 40% risk of injury while 3 inches is associated with a 95% risk of injury.

Horsch (1991) demonstrated that the location of the belt on the shoulder and pelvis of the dummy influenced the measured chest deflection. As a result, the actual chest deflection of a car occupant under similar conditions was underestimated using the Hybrid III dummy in many instances. Horsch et al. (1991) analyzed field data and equivalent tests with Hybrid III dummy and determined that 40 mm of Hybrid III chest deflection for belt restrained occupants was associated with a 25% risk of an AIS$3 thoracic injury.

Horsch and Schneider (1988) reported that the Hybrid III dummy demonstrates biofidelity at and above 4.6 m/s impact velocity but it may be stiffer than the human chest at lower impact velocities. Sled tests at 30 mph using the Hybrid III dummy with belt restraints or airbag restraints suggested that the chest compression velocity was approximately 2 to 3.5 m/sec and so the dummy chest would behave stiffer than a human chest under belt or airbag restraint environments. Therefore, injury assessment based on chest deflection measured in the Hybrid III chest under belt or airbag restraints in a 30 mph crash would under predict the actual injury outcome. Hence, this suggests that even the recommended injury criteria of 65 mm maximum chest deflection may be high.

4.2 ANALYSIS OF HUMAN SURROGATE TEST DATA

Data available in NHTSA's Biomechanics database from sled tests using human surrogates were analyzed to establish a thoracic injury criterion with improved injury predictive capabilities over other existing criteria. A total of seventy one frontal impact sled tests from three different impact trauma laboratories were examined and analyzed using logistic regression as discussed in Chapter 1. Data from fifty-four of these sled tests have previously been published. (Morgan, 1994). In each test, the human surrogate was restrained by one of five possible system configurations at the driver's position: (1) 3-point belt, (2) 2-point belt/knee bolster, (3) driver airbag and lap belt, (4) driver airbag and knee bolster, and (5) combined driver airbag and 3-point belt. The change in velocity ()V) of these tests ranged from 23 to 56 km/h. Following the tests, the surrogates were radiographed and necropsied to delineate any trauma that occurred during the impact event. The level or severity of injury was coded using the 1990 AIS manual. All AIS$3 injury in these tests involved rib fractures or associated soft tissue lacerations. The mean age of the human surrogates was 60 years and the mean mass was about 70 kg. After the publication of the biomechanics report with the NPRM (Docket 98-4405-9) (Kleinberger, et al., 1998), minor errors in the data set were identified and subsequently corrected. The sled test data is presented in Table 4-1 with the shaded cells representing corrected values.

Human surrogates were fitted with tri-axial accelerometers at the first thoracic vertebrae. Chestbands (Eppinger, 1989) were wrapped around the chest at the location of the fourth and the eighth rib to obtain continuous measurements of chest deformations during impact. Chest deflections at five different locations UL, UC, UR, LL, and LR on the chest (Figure 4-1) were obtained by tracking the distance between pairs of points on the periphery. Chest deflections were then normalized by the chest depth of the specimen. Chest deflection was differentiated to obtain rate of deflection, from which velocity V and V*C were computed. The chest deflection and rate of deflection obtained from chestband data are external measurements which include the deflection and rate of deflection of the skin and flesh as well as those of the ribs.

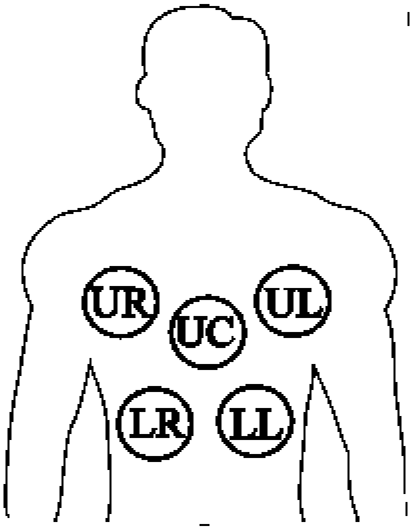

Figure 4-1. Location of five chest deflection measurement sites.

Table 4.1

Details of The 71 Sled Tests Using Human Surrogates

TESTID	VELOCITY	RESTRAINT	AGE	SEX	MASS	AIS	RIB	A	MAX. NORMALIZED DEFLECTION					MAX. INSTANT. EXTERNAL VEL. (m/					MAX. V*C
	(kph)	TYPE			(kg)		FX	g's	UL	UC	UR	LL	LR	UL	UC	UR	LL	LR	(m/sec)
ASTS47	33.50	3PT	65	M	66	1	1		0.15	0.21	0.26	0.00	0.15	1.66	1.53	1.73	0.74	1.58	0.29
ASTS53	34.90	2PT/KNE	61	F	61	3	21	38.07	0.25	0.31	0.39	0.00	0.07	3.98	2.77	2.64	1.11	1.72	0.64
ASTS61	46.70	3PT/DPL	62	M	66	4	23	42.58	0.23	0.30	0.26	0.29	0.33	2.69	3.78	3.12	4.86	2.86	0.97
ASTS66	48.30	3PT/DPL	53	M	51	3	20		0.28	0.28	0.26	0.11	0.21	3.71	1.97	2.32	1.45	2.59	0.50
ASTS79	48.00	3PT/DPL	68	M	66	4	19	42.36	0.36	0.35	0.22	0.04	0.32	2.79	2.74	2.34	0.95	2.45	0.71
ASTS93	48.80	ABG/KNE	66	M	89	4	25	66.99	0.26	0.32	0.38	0.27	0.32	5.91	7.33	9.02	4.96	5.55	2.28
ASTS94	49.60	ABG/KNE	66	F	62	5	20	88.17	0.25	0.26	0.26	0.23	0.34	2.71	2.46	2.00	3.58	5.41	1.41
ASTS96	34.00	ABG/KNE	58	F	97	4	14	111.54	0.05	0.05	0.05	0.05	0.07	2.02	1.73	2.15	1.30	1.37	0.06
ASTS97	33.50	ABG/KNE	67	M	74	5	14	70.42	0.11	0.13	0.14	0.13	0.13	1.38	1.51	1.55	3.01	1.78	0.26
ASTS102	33.20	2PT/KNE	60	M	95	5	19	25.27	0.22	0.30	0.32	0.06	0.18	4.00	4.98	4.49	1.33	2.23	1.30
ASTS103	32.50	2PT/KNE	57	M	102	5	13		0.11	0.12	0.16	0.06	0.08	3.56	5.19	5.91	2.03	2.28	0.38
ASTS104	32.30	2PT/KNE	66	F	104	5	11	28.22	0.40	0.52	0.43	0.00	0.31	2.30	3.23	3.34	0.62	2.42	1.03
ASTS113	47.30	2PT/KNE	24	F	57	5	12	43.37	0.33	0.40	0.29	0.12	0.20	1.65	1.96	1.42	1.89	1.65	0.53
ASTS174	25.90	3PT/KNE	57	F	61	3	12	29.74	0.24	0.33	0.33	0.01	0.03	2.51	3.21	2.94	0.66	1.00	0.97
ASTS175	25.70	3PT/KNE	58	M	116	2	3	28.33	0.25	0.32	0.25	0.06	0.18	2.68	2.99	2.25	0.67	1.75	0.64
ASTS223	54.90	2PT/KNE	51	M	61	4	13	47.30	0.40	0.45	0.30	0.00	0.17	2.60	3.10	2.15	0.56	1.57	0.77
ASTS224	54.30	2PT/KNE	58	M	65	4	16	42.30	0.22	0.34	0.44	0.08	0.16	2.23	2.92	3.18	3.98	1.56	0.90
ASTS225	53.90	2PT/KNE	36	M	72	4	16	43.10	0.32	0.22	0.13	0.02	0.31	4.13	3.59	2.44	0.87	4.77	1.04
ASTS227	53.50	2PT/KNE	53	M	70	3	12	50.73	0.36	0.39	0.37	0.01	0.19	8.51	8.00	5.75	1.10	1.91	2.21
ASTS228	54.70	2PT/KNE	47	M	84	4	16	43.28	0.22	0.34	0.42	0.04	0.20	6.24	7.89	9.94	2.30	2.87	2.95
ASTS229	54.00	2PT/KNE	37	M	60	4	17	46.94	0.27	0.19	0.13	0.06	0.36	3.56	2.88	2.06	1.12	3.55	1.00
ASTS250	54.90	2PT/KNE	39	M	50	4	12	54.04	0.17	0.13	0.10	0.04	0.09	2.68	2.64	2.41	0.66	0.65	0.34
ASTS258	55.40	2PT/KNE	69	M	64	3	14	54.31	0.20	0.27	0.31	0.05	0.19	2.85	3.67	4.55	1.31	2.71	0.82
ASTS259	56.40	2PT/KNE	64	F	77	4	15	80.83	0.09	0.13	0.17	0.00	0.06	1.38	1.96	2.60	0.46	0.77	0.23
ASTS294	56.80	3PT/KNE	68	F	55	4	10	62.00	0.22	0.31	0.38	0.26	0.26	2.92	2.66	3.08	5.36	2.72	0.94
ASTS296	59.80	3PT/KNE	59	M	73	4	26	61.60	0.29	0.41	0.36	0.04	0.25	2.95	3.52	3.27	0.87	2.67	1.13
ASTS303	57.50	3PT/ABG	64	M	50	2	4	51.94	0.16	0.12	0.08	0.00	0.11	2.61	1.70	1.43	0.44	1.56	0.13
ASTS304	59.40	3PT/ABG	65	M	57	4	15	67.62	0.30	0.34	0.25	0.01	0.16	3.11	3.75	3.19	0.99	3.24	0.85
ASTS305	59.40	3PT/ABG	66	F	58	4	12	67.64	0.40	0.37	0.29	0.02	0.19	3.30	3.03	2.60	0.90	2.22	0.77
UVA333	58.20	3PT/ABG	50	M	64	3	6	78.70	0.18	0.19	0.14	0.00	0.07	1.72	1.82	1.44	0.54	0.94	0.28
UVA334	58.20	3PT/ABG	47	M	79	3	5	72.89	0.23	0.23	0.24	0.01	0.13	1.38	1.36	1.44	1.14	1.70	0.30
UVA335	58.60	3PT/ABG	69	M	66	2	2	52.13	0.15	0.12	0.08	0.02	0.10	1.89	2.61	2.52	0.62	0.82	0.11
UVA356	57.20	ABG/KNE	64	M	74	4	30	60.07	0.20	0.23	0.25	0.32	0.28	4.63	4.37	4.22	6.16	3.73	1.04
UVA357	57.20	ABG/KNE	48	M	80	5	19	75.95	0.21	0.23	0.23	0.31	0.31	3.63	4.05	3.74	4.48	4.23	0.64
UVA358	59.00	ABG/KNE	40	M	81	4	17	56.60	0.13	0.15	0.15	0.20	0.27	1.29	1.57	1.51	2.78	3.35	0.48

Table 4.1 (Continued)

TESTID	VELOCITY (kph)	RESTRAINT TYPE	AGE	SEX	MASS (kg)	AIS	RIB FX	A g's	MAX. NORMALIZED DEFLECTION					MAX. INSTANT. EXTERNAL VEL. (m/s)					MAX. V*C (m/sec)
									UL	UC	UR	LL	LR	UL	UC	UR	LL	LR	
H9013	48.00	3PT/KNE	34	M	71	0	0	27.23	0.40	0.44	0.32	0.09	0.09	4.08	4.15	3.07	6.51	1.83	1.33
H9207	48.60	ABG/KNE	25	M	74	0	0	48.54	0.08	0.11	0.12	0.11	0.14	1.15	1.49	1.29	2.05	1.59	0.19
H9212	48.00	ABG/KNE	38	M	79	0	0	45.65	0.14	0.16	0.14	0.13	0.07	2.05	2.24	2.11	2.41	2.02	0.23
H9216	48.00	3PT/KNE	20	M	86	2	0	33.68	0.25	0.18	0.10	0.01	0.05	2.30	2.64	2.17	1.04	1.00	0.47
H9310	48.00	3PT/KNE	52	F	68	2	1	28.78	0.30	0.27	0.19	0.02	0.13	2.34	2.01	1.53	0.78	1.38	0.40
H9311	48.00	ABG/3PT	47	F	76	2	0	31.28	0.17	0.24	0.19	0.04	0.19	1.83	2.56	2.15	1.01	1.37	0.39
H9312	48.00	ABG/3PT	32	M	85	2	3	31.54	0.14	0.16	0.14	0.01	0.17	2.06	2.14	1.68	1.36	1.63	0.20
RC101	49.90	3PT	58	M	85	4	10	39.92	0.10	0.12	0.11	0.11	0.34	2.97	3.45	4.03	2.53	4.05	1.23
RC102	48.30	3PT	58	M	73	4	12	89.53	0.17	0.22	0.16	0.14	0.49	3.53	3.87	3.30	1.41	3.19	1.17
RC103	48.30	3PT	66	M	76	3	8		0.42	0.51	0.43	0.09	0.11				2.22	2.61	0.18
RC104	48.30	3PT	58	M	70	3	13	40.47	0.04	0.13	0.17	0.03	0.16	1.85	1.77	2.28	1.21	3.38	0.41
RC105	48.30	3PT	67	M	73	3	19	72.89	0.40	0.43	0.40	0.09	0.29	10.51	9.28	5.11	1.39	3.77	3.14
RC106	48.30	3PT	44	M	90	4	9	53.00	0.32	0.34	0.31	0.00	0.07	11.98	12.46	9.61	1.97	2.42	2.28
RC107	48.30	3PT	63	F	77	4	22	46.58	0.39	0.37	0.26	0.17	0.28	2.79	2.69	2.51	2.23	3.70	0.91
RC108	48.30	3PT	57	M	73	4	8	54.87	0.35	0.22	0.12	0.08	0.03	7.90	6.09	4.22	1.47	1.32	2.19
RC109	48.30	3PT	59	M	91	3	12	32.33	0.27	0.36	0.46	0.14	0.22	4.96	5.40	5.15	6.62	3.41	2.05
RC110	48.30	3PT	63	F	61	4	24	56.40	0.11	0.24	0.34	0.05	0.35	8.06	7.06	7.91	1.05	4.66	1.73
RC112	48.30	ABG/LAP	67	F	50	2	3	43.96	0.12	0.16	0.18	0.01	0.00	2.13	2.70	2.99	1.01	0.83	0.37
RC113	48.30	ABG/LAP	64	M	70	2	3	43.27	0.36	0.33	0.30	0.04	0.08	3.53	3.75	3.50	2.48	2.77	0.78
RC114	48.30	ABG/LAP	58	M	73	0	0	59.66	0.24	0.23	0.20	0.21	0.14	4.91	5.07	4.37	3.28	2.45	0.58
RC115	48.30	ABG/3PT	67	F	57	3	13		0.23	0.29	0.33	0.17	0.28	3.85	5.62	3.49	3.57	3.61	0.76
RC116	48.30	ABG/3PT	68	M	59	4	10	28.80	0.31	0.26	0.22	0.10	0.10	3.05	2.53	2.44	2.46	2.31	0.64
RC117	23.20	3PT	76	M	58	3	9	23.51	0.19	0.25	0.26	0.01	0.17	3.14	4.06	3.59	0.41	1.81	0.83
RC118	46.50	ABG/KNE	29	F	41	0	0	44.04	0.19	0.21	0.19	0.15	0.27	1.41	2.25	2.33	1.25	3.29	0.35
RC119	45.40	ABG/KNE	71	M	81	4	11	53.71	0.20	0.24	0.28	0.35	0.41	7.66	9.54	11.06	11.87	9.48	3.05
RC120	23.50	3PT	51	M	66	3	8	21.73	0.40	0.36	0.28	0.26	0.22	2.51	2.53	2.32	2.24	2.34	0.85
RC121	24.50	3PT	67	M	66	0	0	16.21	0.26	0.23	0.18	0.03	0.09	2.06	1.87	1.70	0.57	1.14	0.40
RC122	23.70	3PT	81	F	60	2	4	15.17	0.21	0.24	0.20	0.04	0.13	1.28	1.49	1.28	0.73	1.24	0.19
RC123	23.70	3PT	67	F	68	2	1	15.84	0.26	0.22	0.15	0.01	0.16	1.75	1.63	1.18	0.44	1.47	0.27
RC124	31.60	ABG/KNE	76	M	80	0	0	18.40	0.16	0.19	0.19	0.24	0.20	6.16	5.31	3.16	3.71	2.67	0.44
RC125	43.80	ABG/KNE	75	F	85	3	10	45.55	0.23	0.26	0.27	0.32	0.31	1.64	3.00	3.48	3.69	3.51	1.01
RC126	34.70	ABG/KNE	64	F	54	3	6	26.85	0.18	0.18	0.15	0.27	0.37	1.16	1.37	1.35	4.91	5.11	1.08
RC127	34.40	ABG/KNE	81	M	62	2	3	20.61	0.12	0.11	0.11	0.14	0.18	2.05	1.35	1.29	1.51	2.51	0.33
RC128	29.90	ABG/3PT	67	F	46	2	3	23.10	0.34	0.34	0.26	0.05	0.20	2.32	2.37	2.01	0.54	2.09	0.48
RC129	32.80	ABG/LAP	59	M	78	3	8		0.15	0.17	0.17	0.19	0.10	1.99	2.27	2.16	4.69	3.42	0.63
RC130	32.70	ABG/3PT	56	M	63	2	4		0.17	0.19	0.13	0.04	0.12	1.46	1.72	1.46	0.68	1.49	0.25

After the publication of the previous report, comments from AAMA and Ford Motor Co. suggested that some tests in the data set appear to be outliers in terms of restraint performance. In particular, in four sled tests conducted at the University of Virginia with air bag/knee bolster restraints (ASTS93, ASTS94, ASTS96, and ASTS97), the occupant's head hit the sun visor resulting in very high spinal acceleration to the occupant. Since the large spinal acceleration were not due to chest loading but due to head contact, these four tests were not considered for further analysis. Further, in four tests using 2-point belt restraints conducted at an impact velocity of 33 kph (ASTS102, ASTS103, ASTS104, and ASTS113), the occupant sustained AIS 5 injuries while in similar tests at higher velocities the occupant sustained less than AIS 5 injuries. The higher AIS values for these tests may be due to difference in autopsy reporting. Due to this unexplained discrepancy, these four tests were also not considered in further analysis. Therefore, out of 71 sled tests, 63 tests were used for the revised analysis presented in this report.

Statistical analyses were conducted using the 3 millisecond clip value of thoracic spine resultant acceleration (A_s), maximum normalized central chest deflection (dc) corresponding to the location of chest deflection measurement on the Hybrid III dummy, maximum normalized chest deflection at any one of the five locations on the chest (dmax), maximum chest velocity (V), and the maximum Viscous Criterion (VC) at any one of the five locations on the chest. The statistical analyses were also repeated using the 3 millisecond clip value of thoracic spine resultant acceleration which was normalized by length based on the cube root of the cadaver mass. Since the difference between the results using the unscaled and scaled spinal accelerations was not significant and the unscaled accelerations produced a slightly better fit to the data, the analyses presented use the unscaled spinal accelerations.

Thoracic injury outcomes classified using the AIS scale were reclassified into three categories: all tests with thoracic AIS<3, AIS=3, and AIS>3. Logistic regression was used to develop the various injury criteria models. Model building strategies and goodness of fit measures outlined by Hosmer and Lemeshow (1989) were used to develop the models as well as for comparing their relative predictive ability. The goodness of fit of the model was determined by examining the -2log-likelihood ratio (-2log(LR)) which is a measure of the probability that the independent variables explain the available outcome. The -2 log(LR) is used to test the null hypothesis that the coefficient associated with the independent variable is zero. Under the null hypothesis, -2log(LR) has a chi-square distribution and SAS tests this null hypothesis and provides p-values. Higher values of -2log(LR) and lower p-values indicate that the model provides a better fit to the data. Assuming the null hypothesis is true, the difference in the -2log LR value between one model and another where an extra independent variable is added is a chi-square distribution with one degree of freedom. The null hypothesis that the coefficient associated with the additional variable was tested using this chi-square distribution.

The Goodman-Kruskal Gamma of rank correlation was used for assessing the predictive ability of the model. Similar to R^2 in regression analysis, a Gamma value of 1 indicates perfect predictive ability while a value of 0 indicates no predictive ability of the model. Predictive ability of the model can also be assessed by the percentage of concordance and discordance. The greater the percentage of concordance, the better the predictive ability of the model.

The probability of injury from a logistic regression model is given by $p=(1+e^{-(a+ß*x)})^{-1}$, where x is the value of the risk factor in the model and a and ß are regression coefficients. The first logistic regression analyses were univariate using the single independent variables, A_s, dmax, dc, V, and VC (Table 4-2). The p-value and goodness of fit measures for these analyses suggest that A_s and VC are better predictors of injury than dmax or dc. The results also suggest that dmax is a better predictor of injury than dc.

Next, models using various linear combination of measured parameters were developed. The stepwise selection procedure in logistic regression was used to select combination of variables that best predict injury outcome in the data set. Among all multivariable models examined, a linear combination of chest deflection and spinal acceleration was the best predictor of injury. Model VI is a linear combination of dc and A_s while model VII is a linear combination of dmax and A_s (Table 4-2). The p-value and gamma associated with models VI and VII are higher than the other models suggesting that the linear combination models are better injury predictors than the models using single independent variables (Models I-V). Also, the higher -2Log (LR) value of Model VII over Model VI suggests that model VII is a better fit of the data.

Table 4-2. Details of Logistic Regression Models

Model (a+ß*risk factor)	-2Log(LR)	p-value	concord	discord	Gamma
I. -2.0506+0.063A_s	16.33	0.0001	75.0%	25.0%	0.500
II. -0.031+3.53dc	3.34	0.077	62.8%	37.2%	0.254
III. -2.614+10.877dmax	16.05	0.0001	74.5%	25.5%	0.488
IV. -0.512+1.531VC	14.514	0.0003	74.6%	25.4%	0.496
V. -0.7705+0.3565V	10.54	0.0012	72.4%	26. 6%	0.462
VI. -3.73+0.066A_s+6.07dc	20.41	0.0001	78.4%	21.6%	0.568
VII. -7.13+0.08A_s+14.71dmax	35.56	0.0001	85.4%	14.6%	0.707

Figures 4-2 to 4-4 present the logistic regression injury risk curves (AIS$3) for models I, III, and VII. These models represent respectively the 3 msec clip value of resultant spinal acceleration (As), maximum chest deflection at any one of five measured points (maximum normalized chest deflection, dmax, multiplied by 229 mm representing chest depth of a 50th percentile male), and a linear combination of As and dmax. The linear combination of spinal acceleration and chest deflection (Model VII) separated the AIS$3 observations from the AIS<3 observations better than any of the other models.

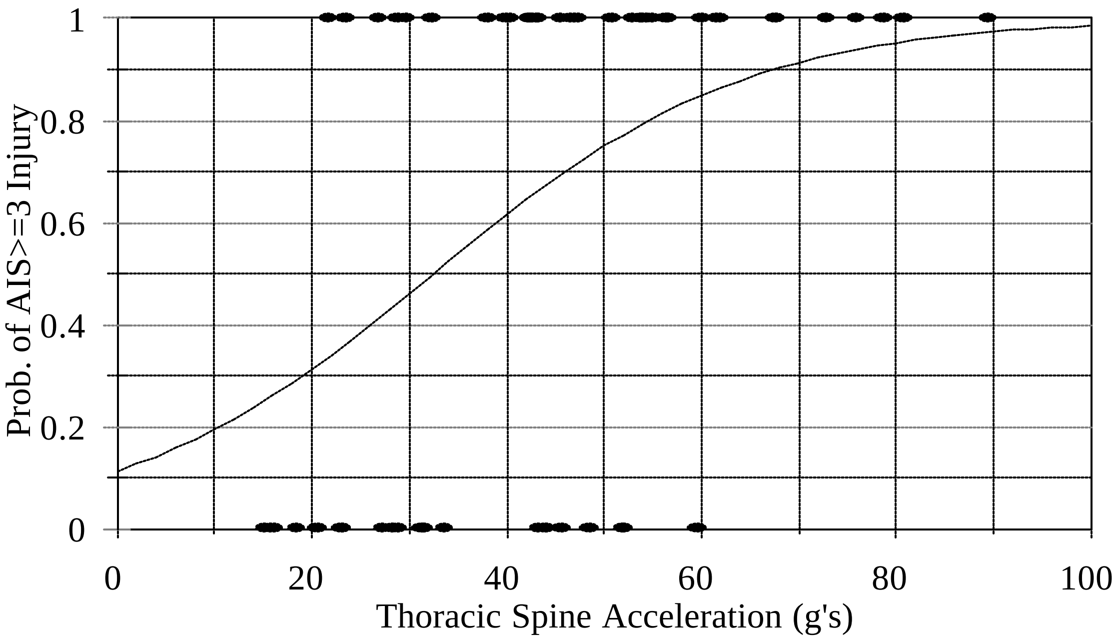

Figure 4-2. Probability of injury using 3-msec clip value of resultant spinal acceleration (As) as risk factor (model I). Filled in circles represent 63 sled test data categorized as AIS$3 injury (=1) and AIS<3 injury (=0).

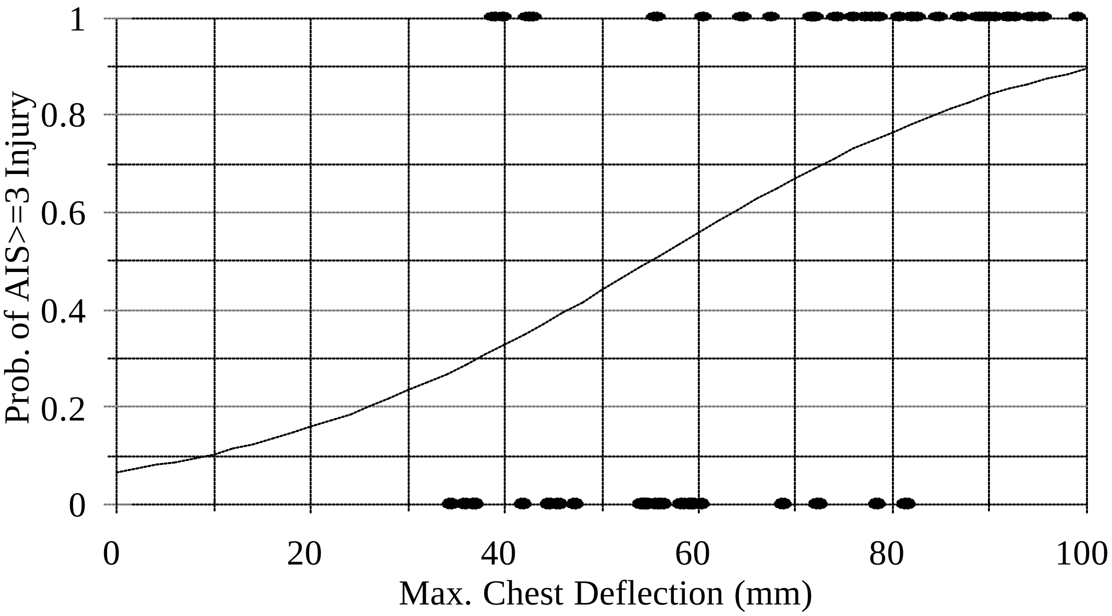

Figure 4-3. Probability of injury using maximum chest deflection (dmax*299 mm) as risk factor (model III).

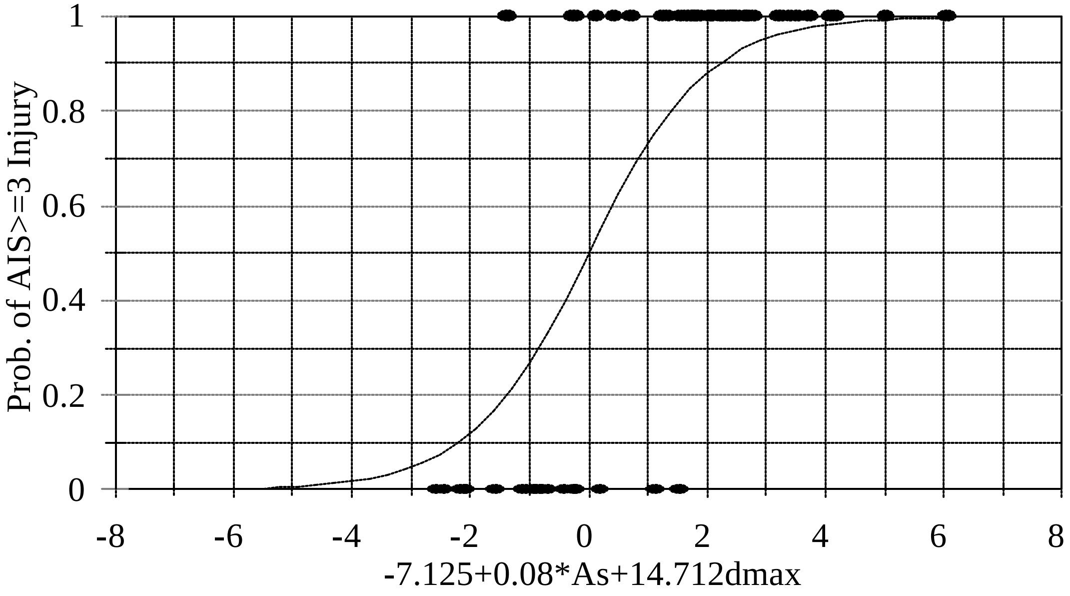

Figure 4-4. Probability of injury using linear combination of dmax and A_s as risk factor (model VII).

The improved predictive abilities of models using dmax over models using dc can be explained by the distribution of the location of maximum deflections. Table 4-3 presents the location of maximum deflection among the five locations on the chest. Maximum chest deflection occurs at the upper central chest location in only 25% of the sled tests. The central chest deflection (dc) versus maximum chest deflection (dmax) for the cadaver sled tests, sorted by the restraint system, is shown in Figure 4-5. The difference between dc and dmax is quite high in some 2 and 3 point belt restrained tests. In these tests, dmax was at the lower chest location of LR while dc is computed at location UC (Figure 4-1). The difference between dc and dmax is also quite high in some airbag restraint tests where the steering wheel rim penetrated into the lower chest resulting in maximum chest deflection at the lower chest location (LL or LR).

Table 4-3 Location of Maximum Deflection in Belt and Airbag Sled Tests

Restraint Type	UL	UC	UR	LL	LR
Belt	15	15	11	0	8
Airbag	1	1	1	4	7
Total	16	16	12	4	15

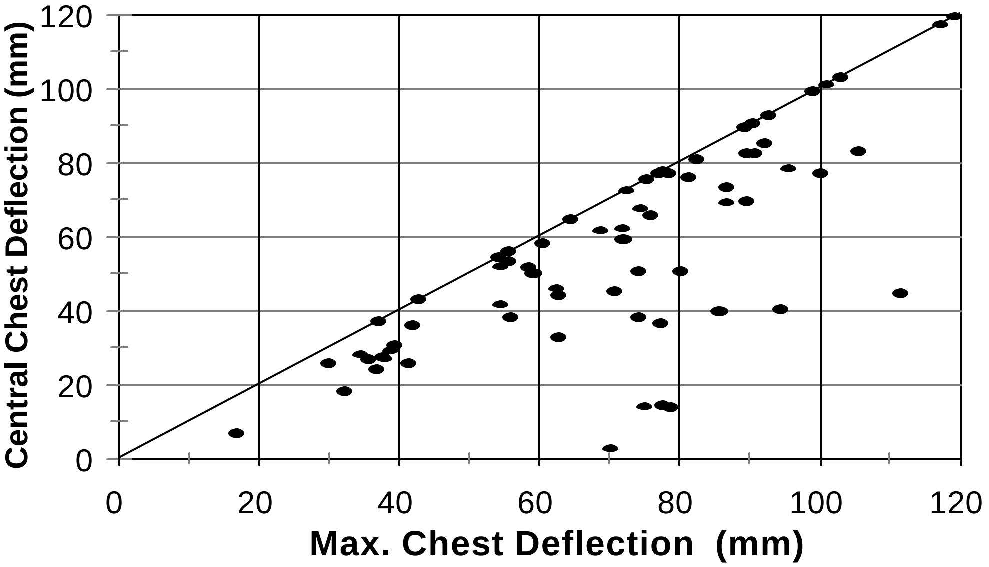

Figure 4-5. Plot of dmax versus dc. Maximum chest deflection occurs at the central chest location in only 25% of the tests.

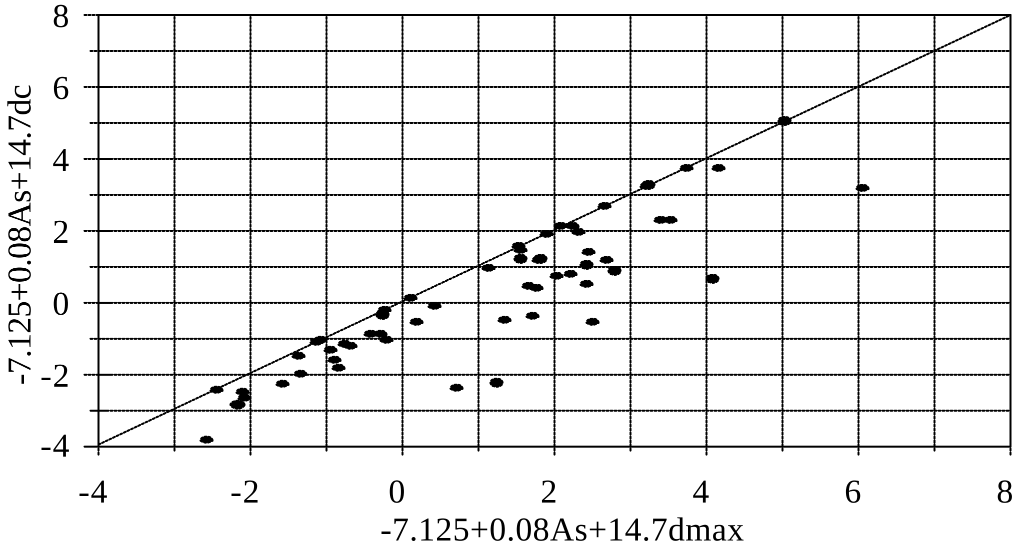

Figure 4-6. Model VII using dmax versus Model VII using dc as an estimator of dmax. The large differences in dmax and dc noted in Figure 4-5 are diminished due to the effect of spinal acceleration.

For the 63 human surrogate tests used in the revised analyses, a 3-msec clip value of spinal acceleration (A_s) has been shown to correlate well with injury since it represents the overall severity of the loading on the subject. For example, in some cadaver sled tests used in the analysis, there was significant steering wheel rim penetration into the lower thorax which resulted in significant injury but presented low chest deflection at the upper thorax. The spinal acceleration in these tests were reasonably high and therefore the linear combination of A_s and dmax proved to be a good predictor of injury. An injury criteria using chest deflection alone may not have predicted the correct injury level under such circumstances as well as the linear combination of deflection and acceleration. The Hybrid III dummy has only one chest deflection gage and it has been noted by various researchers (Backaitis et al., 1986), (Cesari, et al., 1990) that the maximum deflection may be missed in some instances. For these reasons, it is believed that the linear combination model using dmax and A_s is the most appropriate injury criteria for assessing thoracic trauma. However, since only one deflection measurement is available on most dummies, the central chest deflection will be used with this formulation. This will result in slightly lower calculated values for Model VII since dc equals dmax in roughly 20 percent of the tests as described above and shown in Figure 4-6. It is intended that the maximum deflection from multiple points on the chest will be incorporated into the standard when all of the dummies have multiple measurement capabilities.

4.3 DEVELOPMENT OF COMBINED THORACIC INDEX (CTI) FOR THE 50% ADULT MALE

Since the analyses were conducted using normalized deflections, the chest deflections in Model VII, dmax, were multiplied by 229 mm which represents the chest depth of a 50% adult male. The probability of injury function for Model VII can be re-written using the maximum external chest deflection, D, with the following equation,

$$p = \frac{1}{1 + e^{-(-7.125 + 0.08As + 0.064D)}} \tag{4.1}$$

Using this probability of injury equation, lines of equal probability of injury (iso-injury lines) for the linear combination of deflection and spinal acceleration (Model VII) were generated (Figure 4-7).

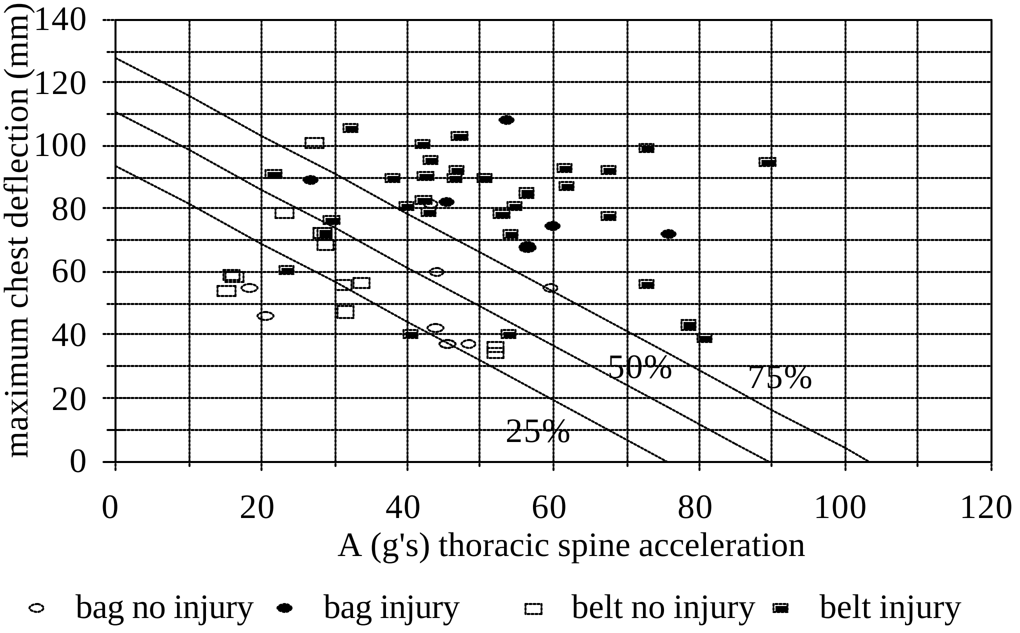

Figure 4-7. Lines of equal probability of AIS≥3 injury using the linear combination of maximum deflection and spinal acceleration (Model VII). The test data categorized into restraint condition and injury outcome is also presented on the graph.

The 50% probability of injury line for the population of human surrogates examined in this data set was used as the injury assessment reference line since it corresponds to about a 25% probability of injury for the live human subjects, as will be discussed in detail in Section 4.5.

Model VII used the normalized external chest deflections, the sum of the deflection of the ribs and skin, measured on cadavers using chest bands. However, the chest deflections measured on the dummy represent only the internal chest deflections of the ribs. To account for the difference between cadaver and dummy deflection measurements, 8 mm was subtracted from the external chest deflection in the 50% probability iso-injury line to represent internal rib deflection measurements. The equation of the 50% probability of injury line using the deflections adjusted for the skin thickness is mathematically equivalent to a line which has intercepts on the vertical and horizontal axes of D_{int}= 103 mm and A_{int} = 90g, respectively. Thus, the combined thoracic injury criteria, CTI, is defined with the following equation,

$$CTI = \frac{A_{\max}}{A_{\text{int}}} + \frac{D_{\max}}{D_{\text{int}}} \qquad (4.2)$$

where Amax is the maximum value of 3 ms clip spinal acceleration (As), Dmax is the maximum value of the dummy deflection (D), and A_{int} and D_{int} are the respective intercepts as defined above.

After the publication of the biomechanics report published with the NPRM (4405-9), AAMA provided an alternate thoracic injury criteria which addresses AIS≥4 thoracic injuries. They argued that since AIS≥3 injuries are predominantly associated with rib fractures and children, in general, seldom have rib fractures, it may be more appropriate to consider AIS≥4 thoracic injuries which constitute both soft tissue and bone injuries. Based on analysis using the Mertz/Weber method on the data published by Neathery (1975), AAMA recommended the chest deflection injury assessment reference value (IARV) in out-of-position and in-position conditions to be 65 mm for the 50th percentile male which corresponds to a 5% probability of an AIS≥4 thoracic injury.

Though the agency believes that the combination of maximum chest acceleration and deflection is a better predictor of injury than individual IARV for chest deflection and acceleration, there are still some questions regarding the interpretation of data used in the development of CTI. Plans for future testing are directed towards answering some of these questions and increasing the number of observations in the data set. Therefore, until more data is available and a reanalysis of the larger data set is conducted to evaluate the efficacy of a CTI based injury criteria, the individual limits of maximum chest acceleration (Ac) and deflection (Dc) will be used for regulation purposes.

In order to harmonize with the IARV used by Transport Canada, the chest deflection limit for the 50% male was taken to be 63 mm (2.5 inches) and 3-msec clip value of resultant chest acceleration limit was taken to be 60 g's. Therefore, the recommended performance limits are Ac=60 g's and Dc=63 mm for the 50% male. The proposed CTI injury criteria from the NPRM will be used for estimating the probability of injury.

4.4 SCALING OF THORACIC INJURY CRITERIA TO VARIOUS OCCUPANT SIZES

As discussed in Chapter 1, scaling techniques are necessary to obtain injury assessment reference values for the various dummy sizes. Thoracic performance limit lines have been scaled using techniques similar to those used by Melvin for the CRABI 6-month infant dummy (Melvin, 1995). Geometric scale factors were taken from Mertz's paper on Injury Assessment Reference Values (Mertz, 1997). In his paper, Melvin discusses the importance of scaling, not only by geometric size, but also by the material stiffness of the biological structures. Dummy chests were designed with varying stiffness to account for changes in material bending properties for different aged occupants. Deflection criteria can thus be scaled using only geometric factors, assuming $\lambda_E = 1$, while acceleration criteria use both geometric and material scaling factors. The relevant scale factors presented in the paper are given in Table 4-4 for reference. Thus, deflections for various dummy sizes, D, or accelerations, A, can be found by scaling as follows:

$$\begin{aligned} D &= \lambda_{L,\,\mathrm{Depth}}\, D_{50\%\,male} \\ A &= \frac{\lambda_E}{\lambda_{L,\,\mathrm{Mass}}}\, A_{50\%\,male} \end{aligned} \tag{4.3}$$

where the IARV for the 50% male dummy are $D_{50\%\mathrm{male}}$ and $A_{50\%\mathrm{male}}$.

Table 4-4. Thoracic Scaling Factors for Various Occupant Sizes

Scale Factor	95th %ile male	50th %ile Male	5th %ile Female	6 Year Old child	3 Year Old Child	12 Month Old Infant
Length Based on Chest Depth $(?_{L, Depth})$	1.107	1.000	0.817	0.617	0.557	0.485
Length Based on Mass $(?_{L, Mass})$	1.090	1.000	0.862	0.650	0.578	0.504
Bone Modulus Scale Factor $(?_E)$	1.000	1.000	*	0.667	0.474	0.320

* Data comparing the modulus and strength of female anatomic structures to male are not available at this time.

The deflection and acceleration intercepts (Aint=90 and Dint=103) for the Combined Thoracic Index for the 50% adult male and the proposed deflection and acceleration performance limits (Ac=60 and Dc=63) were all scaled according to equation 4.3. Melvin (1995) conducted a thorough analysis by examining various scaling techniques and proposed 50 g's as the chest acceleration IARV for the six month old CRABI. However, the scaled chest acceleration for the 12 month old CRABI dummy using Equation 4.3 is only 40 g's. Since we expect the 12 month old to have at least the same, if not a greater, chest acceleration IARV than the 6 month old, the chest acceleration performance limit for the 12 month old was raised from its scaled value to 50 g's. Mertz proposed a chest acceleration IARV of 55 g's for the 3-year old which corresponds to 1% probability of AIS$3 thoracic injury based on an analysis (Mertz/Weber method) of the combined pig data of Prasad/Daniels (1984) and Mertz et al. (1979). However, the scaled acceleration limit of the 3-year old using Equation 4.3 is 50 g's. Since the scaled six year old chest acceleration IARV is 60 g's and we expect the 3 year old IARV to be between the 12 month old and the six year old, chest acceleration performance limit of 55 g's recommended by Mertz was used for the 3-year old dummy. The scaled chest acceleration performance limit for the 5% female dummy is 73 g's. However, it is believed that the lower bone density of the female bone will lower this limit somewhat and so the chest acceleration performance limit for 5th percentile female was taken to be the same as the fiftieth percentile male and equal to 60 g's.

Table 4-5. Scaled Deflection and Acceleration Values for Various Occupant Sizes

Value	95th %ile male	50th %ile Male	5th %ile Female	6 Year Old Child	3 Year Old Child	12 Month Old Infant
Chest Deflection Intercept for CTI (Dint) --for analysis purposes only	114	103 mm (4.0 in)	84 mm (3.3 in)	64 mm (2.47 in)	57 mm (2.2 in)	50 mm (2.0 in)
Chest Acceleration Intercept for CTI (Aint)--for analysis purposes only	83	90	90	90	74	57
Chest Deflection Limit for Thoracic Injury (Dc)	70	63 mm (2.5 in)	52 mm (2.0 in)	40 mm (1.6 in)	34 mm (1.3 in)	30 mm** (1.2 in)
Chest Acceleration limit for Thoracic Injury (Ac)	55	60	60*	60	55[+]	50[*+]

*Although geometric scaling alone would predict higher A_c values for females, it is believed that lower bone mineral density would offset this effect. Therefore, the acceleration tolerance values for small females are kept the same as for mid-sized males.

** The CRABI 12 month old dummy is currently not capable of measuring chest deflection.

[+] The scaled chest acceleration threshold of 50 g's was raised to 55 g's according to analysis by Mertz on the pig data.

[*+] The scaled chest acceleration for the 12 month old CRABI was raised to 50 g's to be consistent with that proposed by Melvin for the 6 month old CRABI

Only the individual deflection (Dc) and chest acceleration (Ac) have been proposed for regulation proposes in the SNPRM. The CTI injury criteria proposed in the NPRM (CTI #1.0 and slightly modified Critical Intercept Values) will be used to estimate the probability of injury for analysis purposes only. Figure 4-8 presents the proposed performance limits for acceleration and deflection for the five dummy sizes in the SNPRM.

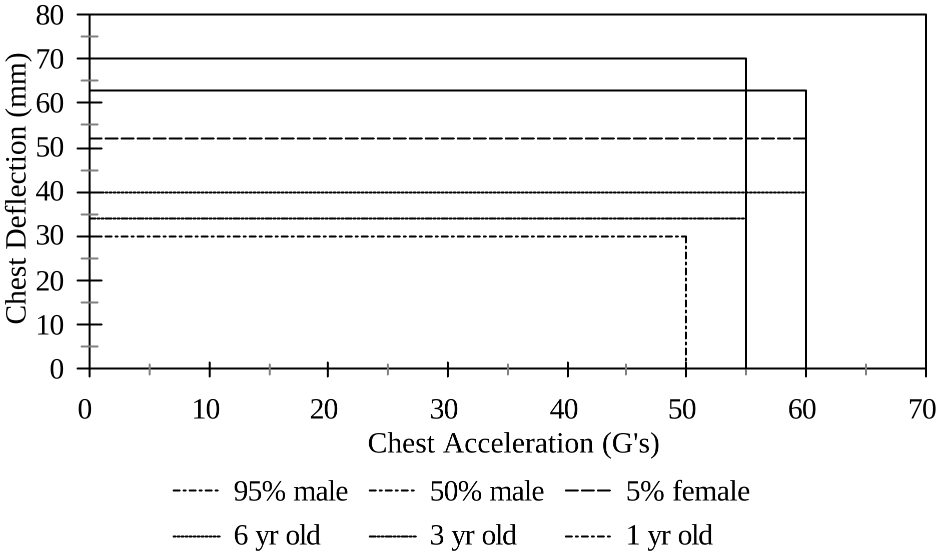

Figure 4-8. Proposed chest acceleration and deflection performance limits for all dummy sizes.

4.5 DEVELOPMENT OF PROBABILITY OF INJURY RISK CURVES FOR THE THORAX

4.5.1 Adjustment of Risk Curves for Live Human Subjects

Viano et al. (1977) observed statistically significant differences in biomechanical responses and injuries between live and postmortem animals. On an average, the live animals demonstrated 26% lower rib fractures than the postmortem animals for the same level of chest deflection. Horsch et al. (1991) noted that human surrogates are more easily injured than car occupants for similar exposures. This apparent difference in tolerance between car occupants and human surrogate data was also noted by Foret Bruno et al. (1978). Yoganandan et al. (1991) noted that in human surrogate sled tests, there was consistently higher reporting of rib fractures from detailed autopsy than from radiography alone. They noted that for the same crash severity, greater severity injury was reported in human surrogate sled tests than in field data. They attributed these differences to the method of identifying rib fractures and the differences in the dynamic response characteristics of the living human and the surrogate.

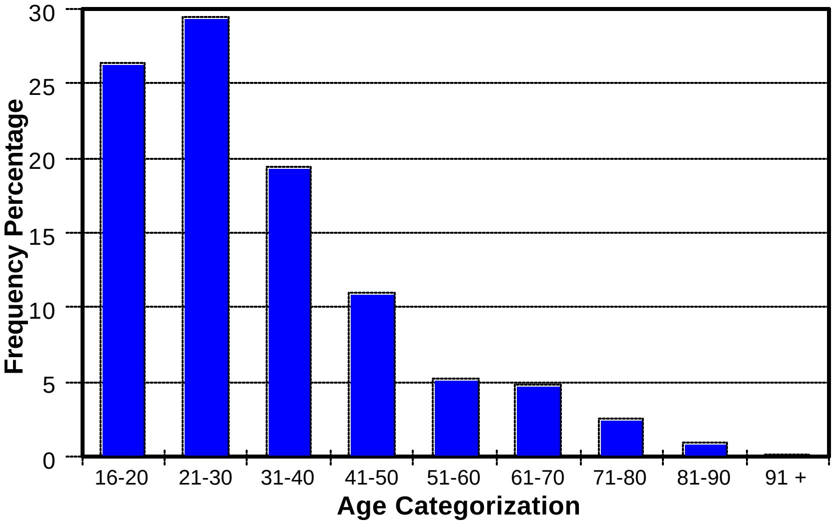

Figure 4-9. Age distribution of the USA driving population exposed to frontal collisions.

The 50% probability of injury line used in the development of the Combined Thoracic Index (Figure 4-7) would represent a significantly lower probability of injury for a car occupant. Figure 4-9 presents the age distribution of the USA population exposed to frontal collisions based on NASS files. The weighted average age of the driving population is approximately 30 years. The average age of the 71 surrogates used in the sled tests is 58 years. Thus, there was a nearly thirty year difference in average age of the surrogate data as compared to that of the average driving population. This thirty year age difference, the increased fragility of cadavers, and the over reporting of injury in experimental tests suggested an adjustment in the probability of injury to represent the probability of AIS$3 thoracic injury for the average live human driving population. Based on all these factors, the 50% probability of injury line in Figure 4-7 was adjusted to represent a 25% probability of injury level for the live human driving population. The adjusted probability of injury curve written in terms of CTI (defined in Equation 4.2) and the original unadjusted curve are shown in Figure 4-10.

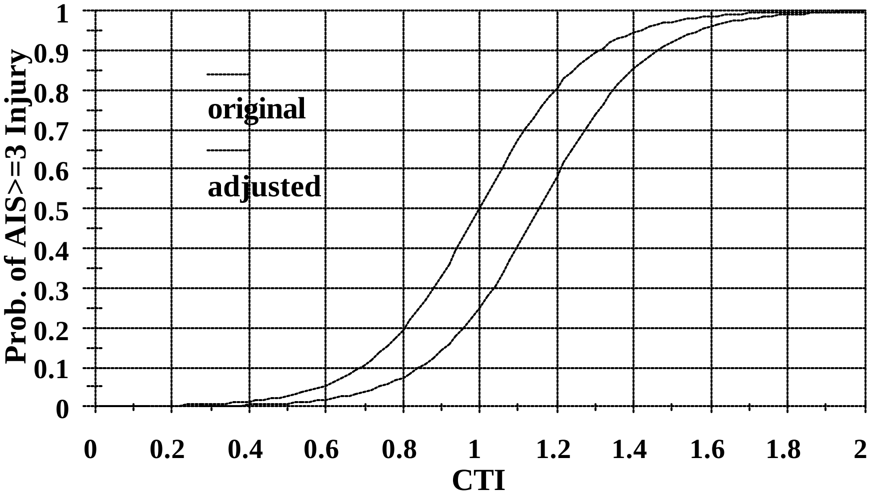

Figure 4-10. Reduced probability of injury using Model VII as the risk factor to relate sled test data to real world crashes. A value of one corresponds to 25% probability of injury.

Data from the 63 human surrogate tests were also reanalyzed using logistic regression to determine the probability of AIS$2, 3, 4, and 5 thoracic injury using chest deflection alone, chest acceleration alone, and the combined CTI.. The resulting AIS$2, 3, 4, and 5 curves were shifted the same amount as the corresponding AIS$3 curve in each case to account for differences between the surrogate test subjects and the average driving population. The probability of injury equations for the adjusted AIS$2, 3, 4, and 5 injury risk curves using maximum chest deflection (Dmax) as illustrated in Figure 4-11, are presented in Equation 4.4. The probability of injury equations for the adjusted AIS$2, 3, 4, and 5 injury risk curves using maximum 3-msec clip value of resultant spinal acceleration (Amax) as illustrated in Figure 4-12, are presented in Equation 4.5. The probability of injury equations for the adjusted AIS$2, 3, 4, and 5 injury risk curves using CTI as illustrated in Figure 4-13, are presented in Equation 4.6. The probability of AIS$5 injury is not very reliable since there was only one test with an AIS=5 in the sled test data of 63 observations.

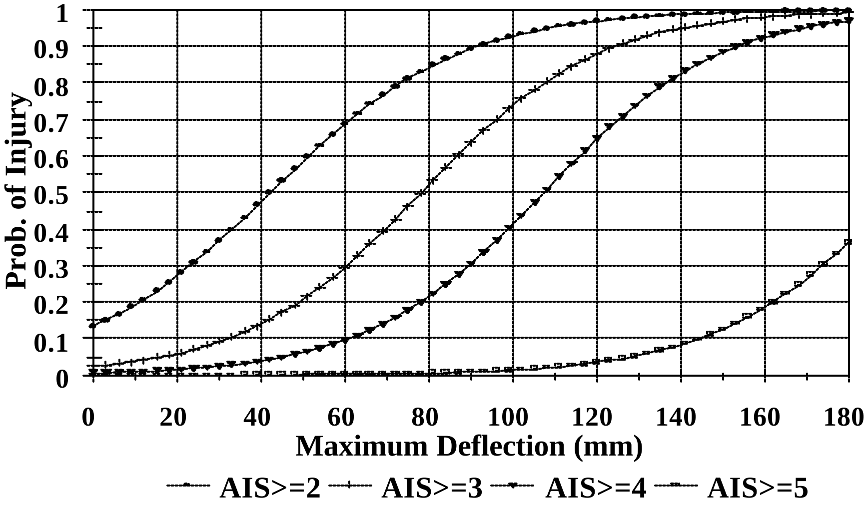

Figure 4-11: AIS 2+, 3+, 4+, and 5+ injury adjusted risk curves for for the Hybrid III 50th percentile male dummy using maximum chest deflection (Dmax).

$$p(\mathrm{AIS} \geq 2) = \frac{1}{1+e^{(1.8706-0.04439\mathrm{Dmax})}}$$

$$p(\mathrm{AIS} \geq 3) = \frac{1}{1+e^{(3.7124-0.0475\mathrm{Dmax})}} \qquad (4.4)$$

$$p(\mathrm{AIS} \geq 4) = \frac{1}{1+e^{(5.0952-0.0475\mathrm{Dmax})}}$$

$$p(\mathrm{AIS} \geq 5) = \frac{1}{1+e^{(8.8274-0.0459\mathrm{Dmax})}}$$

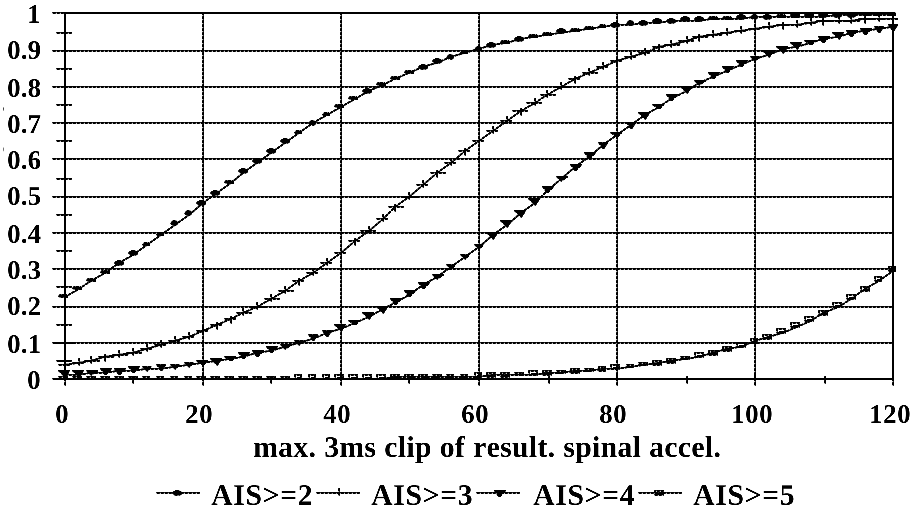

Figure 4-12: AIS 2+ to 5+ adjusted injury risk curves for the 50th percentile Hybrid III dummy using maximum 3-msec clip value of resultant spinal acceleration (Amax).

$$
\begin{aligned}
p(\text{AIS} \geq 2) &= \frac{1}{1+e^{(1.2324-0.0576\text{Ac})}} \\
p(\text{AIS} \geq 3) &= \frac{1}{1+e^{(3.1493-0.0630\text{Ac})}} \\
p(\text{AIS} \geq 4) &= \frac{1}{1+e^{(4.3425-0.0630\text{Ac})}} \\
p(\text{AIS} \geq 5) &= \frac{1}{1+e^{(8.7652-0.0659\text{Ac})}}
\end{aligned}
\qquad (4.5)
$$

$$
\begin{aligned}
p(\text{AIS} \geq 2) &= \frac{1}{1+e^{(4.847-6.036\text{CTI})}} \\
p(\text{AIS} \geq 3) &= \frac{1}{1+e^{(8.224-7.125\text{CTI})}} \\
p(\text{AIS} \geq 4) &= \frac{1}{1+e^{(9.872-7.125\text{CTI})}} \\
p(\text{AIS} \geq 5) &= \frac{1}{1+e^{(14.242-6.589\text{CTI})}}
\end{aligned}
\qquad (4.6)
$$

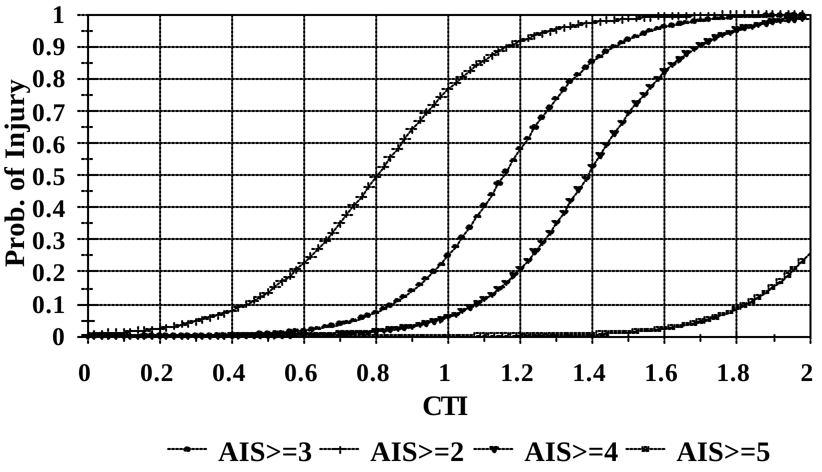

Figure 4-12: Adjusted Risk curves for AIS 2+, 3+, 4+, and 5+ injury using CTI (for all dummies).

To verify that the thoracic injury risk curve was reasonable, comparisons were made between the injury rates predicted using CTI calculations from experimental test data and real world injury rates estimated from the NASS database. NASS data for front seat outboard occupants involved in frontal, non-rollover crashes from 1988 to 1996 were analyzed to determine whether weighted injury probabilities estimated from NASS were reasonably close to those predicted by CTI and the individual performance limit using vehicle crash test data gathered from FMVSS No. 208 compliance testing and NCAP testing.

Results of the NASS data analysis suggested that for unbelted occupants in similar crash conditions as the FMVSS 208 tests (delta-V $ 30), the weighted percentage of front seat occupants with AIS 3+ chest injuries is 25 to 37%. For the 1996-1999 model year vehicles in the FMVSS 208 compliance test data base, the weighted average (weighted by sales volume of each vehicle) percentage probability of AIS$3 thoracic injury estimated using CTI for the driver was 18% and for the passenger 4.5%. Taking into account that 75 percent of all front seat occupants are drivers, the weighted percentage probability of AIS 3+ injuries to front seat occupants, estimated using CTI, is approximately 15%. Thus, for unbelted front seat occupants in high speed crashes, CTI somewhat underestimates the risk of AIS$3 injury based on NASS data.

In contrast, the weighted percentage probability of AIS 3+ injuries estimated using maximum 3-msec clip value of resultant chest acceleration (Amax) alone is 45% for the driver and passenger while that estimated using maximum chest deflection (Dmax) alone is 14.5% for the driver and 6% for the passenger. The joint probability of AIS 3+ injury (assuming independence of events) is 53% for the driver and 48% for the passenger. Taking into account that 75% of front seat occupants are drivers, the weighted percentage probability of front seat occupants, estimated from the individual injury criteria using Dmax and Amax is 52%. Therefore, the individual injury criteria grossly overestimate the risk of AIS$3 injury for unbelted front seat occupants in high speed crashes based on NASS data.

For crashes comparable to NCAP test conditions, NASS data indicates a weighted percentage of front seat occupants with AIS$3 injury of 16 to 17 percent. A similar analysis procedure was applied to the 1996-1999 NCAP test data as that conducted using the FMVSS 208 compliance test data described above. The analysis of NCAP test data suggests that the weighted percentage probability of AIS 3+ injuries for front seat occupants, estimated using CTI, is 16%. In contrast the weighted percentage probability of AIS 3+ injury for front seat occupants, estimated using the individual chest deflection and acceleration injury criteria, is 55%. The individual injury criteria grossly overestimate the risk of AIS$3 injury for belted front seat occupants in high speed crashes while CTI provides a reasonable estimate of AIS 3+ injury based on NASS data.

Looking at both belted and unbelted vehicle occupants, the adjusted probability of injury curve developed for the Combined Thoracic Index (CTI)seems to reasonably represent the injury frequency in real world crashes, while the individual performance limits of chest deflection and acceleration grossly overestimate the risk of AIS$3 injury in real world crashes.

4.6 RATE OF STERNAL DEFLECTION

After the publication of the biomechanics report with the NPRM (4405-9), AAMA recommended sternal deflection rate as an appropriate injury predictor for assessing the risk of heart and/or aortic injuries in out-of-position conditions. The AAMA analyzed the combined Prasad/Daniel (1984) and Mertz (1979) pig data using the Mertz/Weber technique to develop an injury risk curve for AIS$4 heart and lung injuries for the 3-year old dummy using the rate of sternal deflection as the risk factor. Based on this analysis, AAMA recommended an IARVof 8 m/s rate of sternal deflection which corresponds to a 5% probability of AIS$4 thoracic injury for the 3-year old. The data was reanalyzed using logistic regression, the results of which correspond to nearly 15% probability of AIS$4 thoracic injury at 8 m/s rate of sternal deflection Figure (4.13).

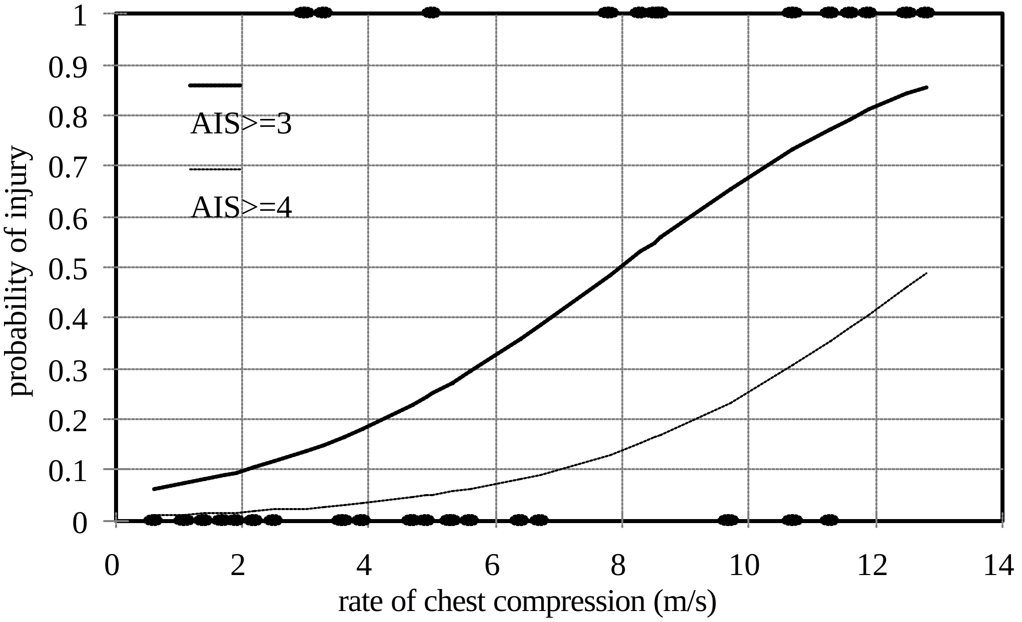

Figure 4.13: Probability of AIS$3 and AIS$4 thoracic injury versus rate of sternal deflection. - developed using Mertz et al. (1979) and Prasad et al. (1984) pig data.

The AAMA applied scaling techniques to determine threshold levels for 5% probability of AIS$4 thoracic injury for the other dummy sizes. AAMA recommended an IARV for rate of sternal deflection of 8.2 m/s for the adult dummies. In out-of-position tests conducted at the University of Virginia using the fifth percentile female Hybrid III dummy (Crandall, 1997), the less aggressive bag registered 8 m/s rate of sternal loading while the more aggressive bag registered approximately 12 m/s. In out of position tests using female cadaveric subjects (Crandall, 1997), the less aggressive air bag caused AIS=3 injury while the more aggressive air bag caused AIS$4 thoracic injury. However, chest deflection was found to correlate better with thoracic injury (r=0.82) than rate of sternal deflection (r=0.49). It should be noted that none of the cadaveric subjects sustained thoracic soft tissue injuries in this series of out-of-position tests which may explain the poor correlation of rate of deflection with injury. Further research is needed to better understand the mechanisms of severe soft tissue injury and to determine soft tissue injury criteria. Due to the limited data available regarding thoracic soft tissue injury, an injury assessment reference value for rate of sternal deflection will not be recommended at the present time. The agency believes that rate of sternal deflection is a good candidate for prediction of heart and aortic injuries and will monitor it in future tests.

4.7 APPLICATION OF PROPOSED THORACIC PERFORMANCE LIMITS TO AVAILABLE TEST DATA

The proposed thoracic injury criteria requires each test to satisfy two performance requirements. These are (1) the 3 ms clip acceleration is less than or equal to Ac, and (2) the maximum chest deflection is less than or equal to Dc. The thoracic injury criteria were calculated for a wide variety of tests available in the NHTSA database. Analyses were conducted for data from 30 mph FMVSS No. 208 compliance tests, 35 mph NCAP tests, 48 kmph rigid barrier and 40 kmph offset tests with 5th percentile female dummies, and out-of-position test with the 6 year-old and 5th percentile female dummies. The accompanying graphs and data for all the tests presented here are provided in detail in Appendices B and D.

4.7.1 Application of Proposed Thoracic Injury Criteria to FMVSS No. 208 Barrier and NCAP Tests

Data from 1996-1999 NCAP crash tests and 1996-1999 FMVSS No. 208 full barrier crash tests were analyzed to determine how various production vehicles performed using the proposed thoracic injury criteria. Figures D.1 - D.4 present the 3 msec clip value of chest acceleration and maximum chest deflection of drivers and passengers in pre-1998 and 1998-1999 vehicles in NCAP and FMVSS No. 208 crash tests along with the thoracic performance limits for the 50th percentile male. The accompanying details of these tests are provided in tables B.1 - B.12.

For the NCAP tests with 1996-1999 model year vehicles, 90% of the drivers and 93% of the passengers passed the chest acceleration performance limit while all the dummies passed the chest deflection performance limit. The percentage of vehicles among the 1996-1999 NCAP tests that pass the chest acceleration and deflection performance limits in each year are presented in Figure 4-14.

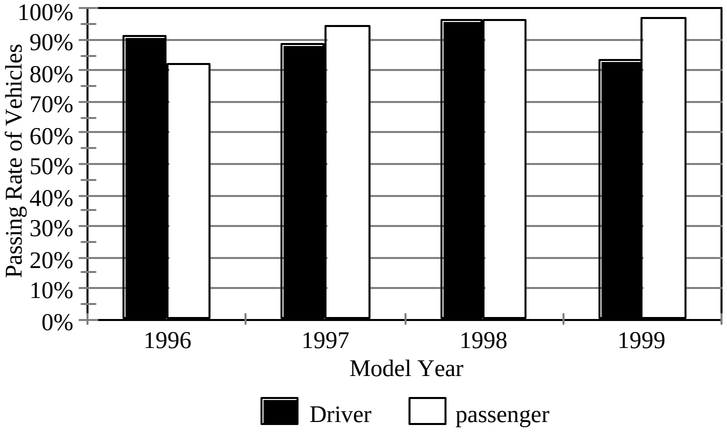

Figure 4.14. Percentage of vehicles passing both the proposed performance limits in NCAP tests by seating position.

For the 1996 - 1999 FMVSS No. 208 barrier tests using the 50th percentile Hybrid III dummy, 98% of the drivers and 93% of the passengers passed the chest acceleration performance limit of 60 g's while all the drivers and passengers passed the chest deflection performance limit of 63 mm. The vehicles which fail the 208 rigid barrier tests for the 1998-1999 years were certified by the sled test option in FMVSS 208.

4.7.2 Application of the Proposed Thoracic Performance Limits to Vehicle Crash Tests with the 5th Percentile Female Dummy

Data from tests conducted at Transport Canada using the Hybrid III 5th percentile female dummy in model year 1998-1999 vehicles were also analyzed. In these tests, the dummy in the driver and passenger position were belt restrained and the seat was adjusted to the full forward position. Figures D.5 - D.8 present the 3 msec clip value of chest acceleration and maximum chest deflection for the various Transport Canada tests along with the thoracic performance limits for the 5th percentile female dummy. The details of these tests are provided in Tables B.13 - B.16.

A series of 48 kmph (30 mph) vehicle crashes of model year 1998-1999 vehicles into a rigid barrier were conducted using the belted 5th percentile adult female dummies in the driver and passenger position seated in the full frontal seat track position. All the drivers and passengers passed the chest deflection and acceleration performance limits except for one passenger whose chest acceleration exceeded 60 g's. The percentage of drivers passing the chest deflection and acceleration performance limits is 100%, while that for passengers is 96%.

Vehicle crash tests into the European deformable barrier at 40 kmph (25 mph) closing speed and a 40% offset were conducted with belted 5th percentile female dummies in model year 1998-1999 vehicles. Such a vehicle crash involves a soft crash pulse which may result in late deployment of the airbag in some vehicles. All dummies in the driver and passenger position passed the thoracic performance limits for chest acceleration (=60 g's) and chest deflection (=52 mm) due to the soft crash pulse.

4.7.3 Application of Proposed Thoracic Performance Limits to Out-of-Position Test Conditions Using the 5th Percentile Adult Female Dummy

Out-of-position tests were conducted to investigate the trauma induced when the vehicle occupant is in close proximity to the deploying airbag. Since fatalities due to airbag interaction have been noted in real world crashes to mainly involve children and small female occupants, out-of-position tests were conducted using the 5th percentile female dummy and the Hybrid III 6-year old dummy.

The driver out of position 1 test condition with the 5th percentile female dummy is intended to maximize head and neck loading from airbag deployment while the out-of-position 2 test condition is intended to maximize chest loading due to air bag deployment. Position 1 and Position 2 out-of-position tests using the 5th percentile female dummy were conducted using 1996-1999 vehicle air bags and the results are presented in Figures D.9 and D.10 and Tables B.19 and B.20. The dummy passed the performance limits of 60 g's chest acceleration and 52 mm chest deflection in all the tests.

4.7.4 Application of Proposed Thoracic Performance Limits to Out-of-Position Test Conditions Using 6-Year Old Dummy

Out-of-position tests were conducted to investigate the trauma induced when the child dummy is in close proximity to the deploying airbag. Two out-of-position test conditions were considered for the 6 year-old Hybrid III dummy. The child OOP position 1 is designed primarily to evaluate contact forces of the deploying airbag on the chest. This position is intended to represent a standardized worst case condition in which the child has been thrown against the frontal structure of the vehicle's interior due to pre-impact braking and/or vehicle impact. The child OOP Position 2 is designed to primarily address the contact forces and loading forces of the deploying airbag on the head and neck. This position is intended to represent a worst case scenario in which the child slides forward or is sitting forward on the seat while the upper torso jack-knifes forward toward the instrument panel.

In the first series of the Position-1 out-of-position tests, 1996-1999 production year air bags were used with zero clearance between the dummy chest and the instrument panel, the results of which are presented in Figure D-11. The chest acceleration performance limit of 60 g's was met in 84% of the tests while the chest deflection performance limit of 40 mm was met in 26% of the tests. In the second series of Position-1 OOP tests, 1996-1998 production year air bags were used with 4 inches of clearance between the dummy chest and the instrument panel, the results of which are presented in Figure D-12. The chest acceleration performance limit of 60 g's was met in all of the tests while the chest deflection performance limit of 40 mm was met in 75% of the tests. In the third series of Position-1 OOP tests, 1996-1998 year air bags were used with 8 inches of clearance between the dummy chest and the instrument panel, the results of which are presented in Figure D-13. The chest acceleration performance limit of 60 g's was met in all of the tests while the chest deflection performance limit of 40 mm was met in 90% of the tests.

Position-2 out-of-position tests with the head of the 6 year old dummy on the instrument panel were conducted, the results of which are presented in Figure D-14. Only 1999 production year air bags were used in these tests. The chest acceleration performance limit of 60 g's was met in 57% of the tests while the chest deflection performance limit of 40 mm was met in 71% of the tests. Details of the Position-1 and Position-2 out-of-position tests are presented in Tables B.21-B.24.

Chapter 5
Lower Extremity Criteria

5.1 FEMUR INJURY CRITERIA

A vast amount of research is currently being conducted to better understand the complex mechanisms of foot and ankle injuries. New dummy legs and associated injury criteria are under development, but are not yet available for use with this standard. Current recommendations are to continue using femur load for the adult dummies, but not for the child dummies. The existing IARV for femur load used in FMVSS 208 is 10 kN for the 50th percentile male. The femur tolerance loads for the 5th percentile female and the 95th percentile male were determined by scaling the 50th percentile male IARV by the femur cross-sectional area scale factor, (Mertz, 1989) presented in Table 5.1. The scale factor for the failure strength and the modulus of elasticity for all three adult sizes is assumed to be 1.

Table 5.1 Femur load IARV and associated scale factor for different size adult dummies

	Hybrid III 5th percentile female	Hybrid III 50th percentile male	Hybrid III 95th percentile male§
Femur Cross-sectional area scale factor	0.682	1.0	1.272
Femur axial force IARV (kN)	6.8	10	12.7

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

Figure 5-1 and Equation 5.1 present the injury risk curve associated with femur loads. A femur load of 10 kN for the mid-sized male dummy represents a 35 percent risk of sustaining an AIS$2 injury. Injury risk values for the small female are assumed to be equivalent to the male risk after application of the scale factor.

$$P(\text{AIS} \geq 2) = \frac{1}{1 + e^{(5.795 - 0.5196 * F)}} \qquad (5.1)$$

where F = femur force in kN

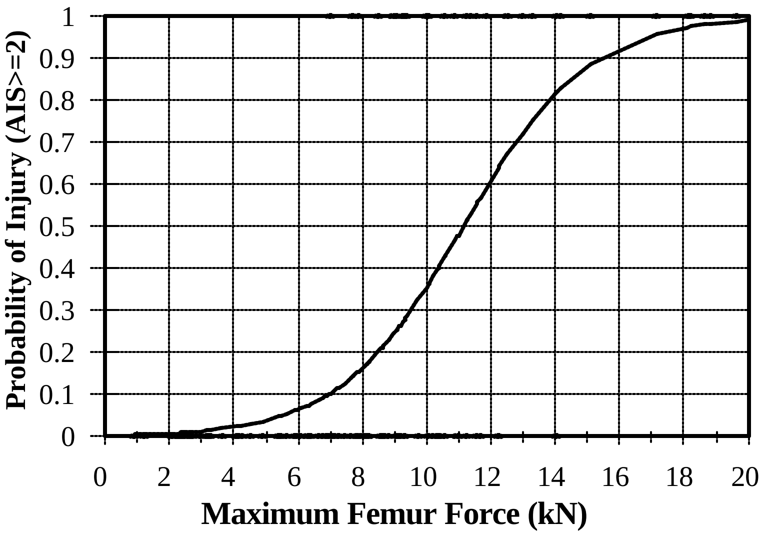

Figure 5-1. Injury risk curve for femur loads.

In response to the NPRM (NHTSA Docket, 4405-9), commenters supported the inclusion of performance limits for femoral compressive loads for the 5th percentile female dummy specified in the NPRM (4405-9) in addition to maintaining the currently specified value for the 50th percentile male dummy. Furthermore, AAMA proposed adding femoral compressive load performance criteria of 2310 N for the 6 YO dummy. The National Transportation Safety Board (NTSB) recommends that tolerance levels of lower extremities need to be further investigated and validated. NTSB also suggests that the NHTSA consider dummies such as advanced lower extremity (ALEX, now called the THOR-LX) dummy for future incorporation into the standards.

Although the NHTSA agrees with the AAMA that femoral compressive load limits for the six year-old dummy are important to consider, the SNPRM does not specify such limits because the testing configurations specified in the SNPRM for the six year-old dummy do not impose substantial loading on the lower extremities. NHTSA is also continuing the development of an advanced lower extremity test device, the THOR-LX, and continues to sponsor experimental impact injury research to determine the mechanisms and tolerances of the lower extremities, including the foot, ankle and leg. When this effort is complete, it is anticipated that this research will be incorporated into future safety standards.

5.2 INJURY CRITERIA FOR THE LEG

Although not proposed in the NPRM (4405-9) or the SNPRM, a modified version of the Tibia Index currently in use by EEVC (Hobbs, 1997) was used for analysis purposes in the regulatory evaluation and is briefly described below. The tibia index was originally proposed by Mertz (Mertz,1993) as an injury tolerance criterion for the leg which combines bending moment and axial compressive loads on the leg as measured by the Hybrid III tibia load cell. The modified version of the tibia index (TI) adopted by EEVC is given by

$$TI = \frac{F}{F_C} + \frac{M}{M_C} \leq 1.3$$

where F is the measured compressive axial force (kN) in the superior-inferior direction. M is the resultant moment of the medial-lateral and the anterior-posterior moments. M_C and F_C are the critical bending moment and critical axial compressive force and are presented in the following table:

	Hybrid III 5th percentile female	Hybrid III 50th percentile male	Hybrid III 95th percentile male
M_C	115 Nm	225 Nm	307 Nm
F_C	22.9 kN	35.9 kN	44.2 kN

The values of M_C and F_C for the 50th percentile male are based on human bone tolerance values obtained from (Yamada, 1970). The critical values for the 5th percentile female and the 95th percentile male were obtained by using scaling relations proposed by Mertz et al. (1989). A TI threshold of 1.3 was recommended and adopted by EEVC (Hobbs, 1997) based on analysis of crash test data.

The Tibia Index assumes that failure of the tibia occurs in compression. However, 3-point bending tests with superimposed axial compression conducted at the University of Virginia suggested that the tibia can fracture in compression or in tension (Schreiber, 1997). Also, Schreiber noted that the critical bending moment used in TI is conservative and underestimates the failure threshold of the leg in bending since the contibution of the fibula and associated leg soft tissue in bending was not taken into consideration.. The magnitude of F_C used in TI is based on the compressive strength of the tibia mid-diaphysis bone segments which is the strongest part of the bone. The distal third region of the tibia has the smallest cross-section and the thinnest cortex and so is more susceptible to failure in compression than the mid-diaphysis. Therefore, the critical compressive force used in the tibia index overestimates the strength of the leg in compression. Another assumption in the application of TI to the Hybrid III dummy is that the Hybrid III leg accurately measures the mid-shaft bending moment and forces that would occur in the human tibia during axial compression of the leg. Crandall et al. (1996) demonstrated that the mass, moment of inertia, and stiffness of the leg and foot of the Hybrid III dummy are quite different from those of the human leg and foot. The structural geometry of the Hybrid III leg and the alignment of the leg shaft with respect to the joint centers is not the same as that of the human. Therefore, the response of the Hybrid III leg is different than that of a human under similar impact conditions.

Chapter 6
Recommendations

Summarizing all of the discussion presented in this paper, Table 6-1 shows the injury criteria and critical values recommended for each body region. HIC$_{15}$ is currently being recommended for head protection, scaled appropriately for all dummy sizes. A neck criteria of SNPRM Nij#1.0 is being recommended, with critical values defined for all dummies. For the chest, the individual limits on chest deflection and spinal acceleration are recommended for regulation with the CTI used for predicting injury probability rates. Femur load is recommended only for the adult dummies.

Table 6-1. Recommended Injury Criteria for FMVSS No. 208 SNPRM

Recommended Criteria	**Large§ Male**	**Mid-Sized Male**	**Small Female**	**6 YO Child**	**3 YO Child**	**1 YO Infant**
Head Criteria: HIC$_{15}$	700	700	700	700	570	390
Neck Criteria: SNPRM Nij	1.0	1.0	1.0	1.0	1.0	1.0
Critical Intercept Values						
Tension and Compression (N)	5440	4500	3370	2800	2120	1465
Flexion (Nm)	415	310	155	93	68	43
Extension (Nm)	166	125	62	39	27	17
Thoracic Criteria						
1. Spine Acceleration (g)	55	60	60	60	55	50
2. Chest Deflection (mm)	70 (2.8 in)	63 (2.5 in)	52 (2.0 in)	40 (1.6 in)	34 (1.4 in)	30* (1.2 in)
Lower Ext. Criteria:						
Femur Load (kN)	12.7	10.0	6.8	NA	NA	NA

§ The Large Male (95th percentile Hybrid III) is not currently proposed for inclusion in the SNPRM, but the performance limits are listed here for completeness.

* The CRABI 12 month old dummy is not currently capable of measuring chest deflection.

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Appendix A

Public Comments on Proposed Injury Criteria

APPENDIX A: Opportunities for Public Comment on Injury Criteria Proposed in the Sept 30, 1998 Publication of the Notice of Proposed Rulemaking for FMVSS No. 208

NHTSA has provided numerous opportunities for all interested parties to submit comments on the proposed injury criteria for review. These include:

1. Written comments submitted to Docket #4405 of the Department of Transportation Document Management System, which may be viewed in Room 401 of the Department of Transportation, 400 7th Street, S.W., Washington, D.C. 20590 or at www.dms.dot.gov.

2. A public meeting held on November 23, 1998 in which technical presentations were made by the agency to describe the basis for the various injury criteria proposed, Mr. Vann Wilber, Director of Vehicle Safety for the American Automobile Manufacturers' Association (AAMA), made a presentation on their views of the proposed rulemaking, and a discussion was held. A summary of this meeting may be found in submission number 89 to Docket #4405.

3. A public meeting held on April 20, 1999 in which additional technical presentations were made by the agency to describe the basis for the various injury criteria proposed and offer additional analyses performed by the agency in response to the comments received. Dr. Harold Mertz of General Motors presented technical material on head injury and neck injury; Dr. Priya Prasad of Ford Motor Company presented a technical analysis on chest injury criteria; and Dr. Guy Nuschultz presented an analysis on statistical analysis techniques. The transcript of this meeting will be submitted to Docket #4405 shortly.

The agency has weighed the relative merit of these comments and has proposed some modified injury criteria in the SNPRM. The following is a detailed summary of the comments received and the agency's response to those comments.

Appendix A: Summary of Comments Submitted to Docket #4405 and Agency Analysis

A.1 General Injury Criteria

NHSTA has proposed to add a new set of requirements to prevent air bags from causing injuries and to expand the existing set of requirements intended to ensure that air bags cushion and protect occupants in frontal crashes. The agency has proposed injury criteria and performance limits that it believes are appropriate for each dummy size, including the 12-month CRABI, 3-year-old, 6-year-old, 5th percentile adult female, and 50th percentile adult male Hybrid III dummies.

Comments Received:

In general, all commenters including manufacturers (BMW, GM, Ford, Mazda), manufacturing associations (AIAM), associations (IIHS, Advocates for Highway Safety, Public Citizens) and citizens (Byron Bloch) strongly supported NHTSA's effort to minimize risks associated with air bag systems by adopting additional anthropometric test devices (ATD) of different sizes with appropriate injury criteria. Commenters' specific remarks on each injury criteria are discussed in the following sections. The following statements summarize the comments on injury criteria in general.

BMW commends NHTSA's efforts to establish new injury criteria. GM, Ford and Mazda support the addition of appropriate injury criteria and additional ATD sizes. A few commenters (AIAM, IIHS, Consumer's Union, Advocates for Highway Safety) emphasized the need for neck injury criteria in the proposed regulation. AIAM believes that the current injury criteria, with the addition of neck criteria, are adequate to ensure the protection of occupants in real-world collisions. IIHS states that based on real-world neck injuries to children, the addition of neck injury criteria are welcome and crucial. The National Transportation Safety Board states that side impact requirements and the corresponding injury criteria need to be reviewed and may need to be addressed in the new standards. The NTSB states that many manufacturers are developing side air bags for the front and rear seats.

A.2 Consensus of International Community and Delayed Introduction of New Injury Criteria

The NPRM proposes two new injury criteria, the neck injury criteria, Nij and the Combined Thoracic Index (CTI), and performance limits for all dummy sizes for in-position and out-of-position testing . Since the current regulation uses only the 50th percentile male dummy, the NPRM specifies performance limits for the existing injury criteria (chest acceleration, chest deflection, HIC, femur loads) for the various dummy sizes. Finally, as an alternative to using Nij, performance limits for current neck injury criteria which are currently used only for the temporary sled test alternative are also specified for the various dummy sizes in both in-position and out-of-position testing. Many comments received, especially regarding the newly proposed injury criteria and the scaling of the injury criteria to various dummy sizes suggested that further discussion and the consensus of the international scientific community was necessary before adopting these criteria and performance limits in a Final Rule.

Comments Received:

A number of commenters (BMW, AIAM, Nissan, Subaru, Mazda, AORC) recommended that a consensus within the international scientific community needs to be reached before new injury criteria are adopted and used as regulatory compliance measures. BMW recommends that the agency follow the recommendations of working group 6 (ISO TC22/SC12), which is comprised of internationally-recognized biomechanics experts. AIAM recommends that the agency convene an international panel of biomechanics experts to review and critique the new criteria before they are adopted, with priority given to scaled criteria for the new dummy sizes. AIAM stated that since it is not critical to include CTI and Nij in the final rule, they recommend postponing their inclusion until the biomechanics community can thoroughly consider their appropriateness. Nissan is concerned that CTI has not been peer-reviewed or otherwise validated by the scientific community. Subaru is concerned that the new injury criteria have not yet been proven by the biomechanics community. Mazda believes that CTI and Nij have not been sufficiently evaluated by the international biomechanics community to be used in regulation. The AORC states that the foundation for all the injury criteria proposed in the NPRM may not have the agreement of biomechanics experts.

Other commenters recommended the inclusion of the new injury criteria with the current rulemaking. Advocates stated that Nij should be included since it offers a more realistic means of measuring neck injury and should offer a more stringent means of preventing significant risk of neck injury. The Center for Auto Safety supports the inclusion of CTI with continued research and Nij with a limit of 1.0. Public Citizens supports the use of new, more sophisticated and realistic means to measure neck and chest injury, specifically Nij with a limit of 1.0 and CTI.

A few commenters, including Subaru, Volvo, Nissan, recommended addressing new injury criteria separately (CTI and/or Nij) from the final rule for FMVSS No. 208. Subaru recommends continued research on the newly proposed injury criteria and review of the new criteria separate from the Final Rule. Volvo believes that chest injury should be evaluated separately from this rulemaking. Nissan recommends directing priority toward the reduction of adverse effects of air bags and the introduction of new injury criteria on a separate basis.

Response to Comments:

The pressing need to minimize the risk to occupants of all sizes in a variety of crash condition precludes the time consuming process of convening a panel of international biomechanics experts and obtaining the consensus of the biomechanics community on the proposed new injury criteria. As an alternative, the agency has provided numerous opportunities for interested parties to submit comments for the agency's review and had considered the viewpoints of each responder. The rationale for maintaining or changing each of the proposed injury criteria will be discussed individually.

NHTSA is continuing to sponsor cooperative research agreements with many of the leading universities in the field of automotive biomechanics to further our knowledge on the mechanisms and tolerance of the human body and to improve scaling procedures to ensure the safety of occupants of all sizes.

A.3: Overview of Comments on Head Injury Criterion

The NPRM proposes that the Head Injury Criterion evaluated over an interval of 36 ms be maintained for the 50th percentile male dummy and scaled for the various sized dummies. The agency requests comments on the proposed injury criterion and performance limits.

Comments Received:

> Two commenters, Volvo and Autoliv, support the performance limits for HIC evaluated over a 36 ms interval for all dummy sizes as proposed in the NPRM. Autoliv accepts the Head Injury Criterion as proposed for all dummy sizes since they appear to be consistent with current risk levels. Autoliv also mentioned that further research on rotational brain injury mechanism might be beneficial. Volvo does not oppose the HIC values for the various dummy sizes proposed in the NPRM, although the reduction for child dummies does not appear to be thoroughly investigated and is lacking biomechanical data to support it.
>
> Two commenters, IIHS and Advocates for Highway Safety, recommend performance limits for HIC that are lower than 660 for the 12 month CRABI dummy. The IIHS recommends a threshold for the 12 month CRABI dummy that is closer to the lowest HIC value of 138 based on different scaling techniques presented in Chapter 3. They state that "adopting the lower value increases the certainty that, if the manufacturers choose to deploy airbags in the presence of rear-facing infant restraints, the airbags would not cause serious brain injury". Advocates states that infants are far more likely to be susceptible to internal organ damage, especially brain trauma and brain swelling, from seemingly benign impacts including those at injury levels below that established for adults.
>
> The National Transportation Safety Board suggested that the NPRM should provide a factor of safety in the HIC performance limits for all child dummies to account for uncertainties in the pediatric skull. The NTSB also states that the NPRM did not provide sufficient information regarding the source or assumptions underlying the HIC scaling factor to allow evaluation of the appropriateness of the HIC scaling factor.
>
> The AAMA proposed evaluating the Head Injury Criterion with a 15 ms interval as is used in the Canadian Federal Motor Vehicle Safety Standard, rather than the 36 ms interval which is currently regulated in the US. In addition, the AAMA proposes using a different statistical technique to analyze the data and using different scaling technique for the various dummy sizes. The HIC values proposed by the AAMA for both in-position and out-of-position testing are summarized in Table A3.1.

Table A3.1: Comparison of NPRM Proposal and AAMA Proposal for the Head Injury Criterion (HIC)

Dummy Size	**AAMA Proposal HIC $_{15}$***	**NPRM Proposal HIC $_{36}$****
CRABI 12 Month	390	660
HIII - 3 yr	570	900
HIII - 6 yr	723	1000
HIII - Small Female	779	1000
HIII - Mid Male	700	1000

* Evaluated over a maximum 15 millisecond interval

** Evaluated over a maximum 36 millisecond interval

Response to Comments:
Comparison of the statistical techniques used by AAMA and the agency may be found in section 1-2.

Based on numerous commenters who suggested lowering the HIC $_{36}$ performance limits for the children, especially the 12 month CRABI, further analyses were performed by the agency on this issue and the AAMA proposal for HIC $_{15}$. A detailed discussion may be found in Chapter 2.

A.4: Overview of Comments on the Neck Injury Criteria

The current FMVSS No. 208 alternative sled test includes injury criteria for Th neck consisting of individual tolerance limits for tension (force stretching the neck), shear (force perpendicular to the neck column), compression (force compressing the neck), flexion moment (forward bending of the neck) and extension moment (rearward bending of the neck). Due to the incidence of neck injuries in the real world data gathered by the National Automotive Sampling System and NHTSA's Special Crash Investigations, the NPRM proposed two alternative methods for assessing the risk of neck injury for the various dummy sizes: (1) Nij, with a value of either 1.0 or 1.4, and (2) independent evaluation of the tension, compression, flexion, extension, forward and rearward shear on the neck. The NPRM requested comments on the two proposed criteria, including the proposed performance limits.

Comments Received:

> A number of commenters (AAMA, DaimlerChrysler, Ford, General Motors, Isuzu, Toyota, Subaru, Mazda, AIAM) strongly oppose the inclusion of Nij in the proposed regulation. The AAMA supports the independent evaluation of neck loads and moments and proposes two separate levels for in-position and out-of-position testing levels based on the protective aspects of passive neck muscle tension (Tables A4.1 and A4.2). A technical discussion of the methodology used by the AAMA to obtain these performance limits is presented in Section 5.2.3. Subaru believes that Nij is not an appropriate injury measure for the wide range of tests proposed in the NPRM, but does not offer further explanation. Although Porsche does not state that they oppose Nij, Porsche points out that Nij is sensitive to small differences in occupants' forward displacement, especially with angled (30 degree) crash tests.

Table A4.1: AAMA Proposed Independent Neck Values for Out-of-Position

Dummy Size	Tension (N)	Compression (N)	Flexion (N-m)	Extension (N-m)
CRABI 12 Month	780	960	27	11
HIII - 3 yr	1130	1380	42	17
HIII - 6 yr	1490	1820	60	24
HIII - Small Female	2070	2520	95	39
HIII - Mid Male	3290	4000	190	77

Table A4.2: AAMA Proposed Independent Neck Values for In-Position

Dummy Size	Tension (N)	Compression (N)	Flexion (N-m)	Extension (N-m)
CRABI 12 Month	780	960	27	11
HIII - 3 yr	1480	1380	42	22
HIII - 6 yr	1910	1820	60	30
HIII - Small Female	2620	2520	95	49
HIII - Mid Male	4170	4000	190	96

Honda, Volvo, and Autoliv support Nij with a preferred maximum of 1.4 at the present time, rather than the independent regulation of neck loads and moments. Based on reasons of practicality, Autoliv states that if a lower value were initially selected, there would be a delay in introduction of advanced safety systems due to more complicated design iterations. Honda supports the performance limit of 1.4, which includes “worst case” tests, due to numerous uncertainties including the appropriate values, the biofidelity of the necks of the various dummies, and the scaling procedures. Honda states that overly severe criteria in one crash scenario could lead to reduced protection in another crash scenario. Volvo states that research indicates that neck injuries is dependent upon a combination (superposition) of the different individual criterion, which justifies the inclusion of Nij as proposed in the NPRM. Volvo states that the proposed individual performance limits for neck injuries, in particular the moments specified for the child dummies, appear to by unjustifiably low and do not appear supported by biomechanical data. Volvo also states that adopting criteria of this stringency without adequate biomechanical data may hamper development of new air bag designs and thus many manufacturers may chose suppression rather than low-risk deployment.

IIHS, Public Citizens, and Advocates for Highway Safety support the neck injury criterion, Nij. IIHS strongly recommends 1.0 as the performance limit to ensure little or no harm to out-of-position occupants. Public Citizens states that Nij seems to be a more sophisticated and realistic way to measure neck injury. Public Citizens supports Nij so long as the forces when combined in the Nij formulation do not exceed the individual performance limits specified in the current sled test alternative in FMVSS No. 208. Furthermore, Public Citizens believes that NHTSA should adopt a more stringent Nij value of 1.0 because it represents significantly reduced risk of serious neck injury and several manufacturers have demonstrated that such a standard is indeed feasible. Advocates for Highway Safety favors the adoption of Nij because it offers a more realistic means of measuring neck injury and should offer a more stringent means of preventing significant risk of neck injury, especially for unbelted children. Advocates supports the introduction of Nij so long as the maximum value of the combination of neck forces and moments do not exceed the limits for the neck criteria when evaluated independently.

Although the National Transportation Safety Board (NTSB) states that there was insufficient details in the NPRM to evaluate the appropriateness of Nij, the NTSB states that a value of Nij equal to 1.0 seems appropriately cautious for children due to uncertainties in the interaction at the occipital condyles of a child, adult, and a porcine model from which the criterion was developed. The NTSB also recommends inclusion of shear and rotational criteria to address neck injury in frontal, side, and combined angle impacts.

The Consumers Union supports the addition of new injury criteria, especially regarding neck injury. The Consumer Union states that their review of films and reports from NHTSA's New Car Assessment Program has shown some "troubling neck motions in some test dummies."

Mazda believes that some type of neck injury criteria are needed for the various dummy sizes based on the nature of the airbag induced injury patterns that are appearing in the field. However, Mazda believes Nij has not been sufficiently evaluated by the international biomechanics community to be used in regulation.

Response to Comments:

Based on the comments received and the discussions at the two public meetings (see summary E-2 and E-3), the agency has opted to continue its support of Nij with a modified formulation. The issue of neck injury, especially to out-of-position adults and children, is one of the priorities of this rulemaking and the agency would be remiss if it did not include the most accurate and up-to-date methods to assess what conditions are injurious and non-injurious. The agency continues to believe that Nij has a strong foundation in biomechanics and testing has shown that the performance limits are practicable or that alternative options, such as suppression systems, are practicable. Although some commenters have suggested that the Nij = 1.0 may be too conservative leading manufacturer's to choose suppression rather than low-risk deployment for the small female and out-of-position children, the agency believes that this stringency is warranted until biomechanical data and field data become available to change this performance limit. The agency also believes that there has been sufficient time and precedence for the evaluation of a formulation of combined loads and moments, similar to Nij. The two parameters, axial force and bending moment at the occipital condyles have long been used to evaluate neck injury. As early as 1984, Prasad and Daniel published a report demonstrating that linear combination of neck loads and moments was a good predictor of neck injury for a series of piglets exposed to air bag deployments. Furthermore in 1996, the agency issued a report describing techniques for developing injury reference value for child dummies which included a combination of neck loads and moments to assess injury. Thus, a modified Nij will remain as the proposal for the SNPRM.

A.5: Overview of Comments on Chest Injury Criteria

For chest injury, NHTSA proposed two alternatives in the NPRM. Under the first alternative, the agency would add the new chest injury criterion, the Combined Thoracic Index (CTI) for use in all test procedures for all dummy sizes. The formulation of CTI is a linear combination of two parameters, chest acceleration and chest deflection, that are currently used independently in FMVSS No. 208. The linear combination of acceleration and deflection was shown in Chapter 4 to be a better predictor of injury in simulated frontal impact conditions than chest acceleration of chest deflection alone. Under the second alternative for chest injury, the agency would simply continue to maintain separate limits on chest acceleration and chest deflection for all dummy sizes. NHTSA requested comments on the two proposed alternative, on how they are calculated, and on the proposed performance limits. In addition, the agency requested comments on whether the same limits should be established for all test requirements, e.g., out-of-position, low speed tests, high speed tests.

Comments Received:

BMW, Isuzu, Daimler Chrysler, Ford, General Motors, Honda, Toyota, Subaru, Volvo, Mazda, Autoliv, AIAM, AAMA, and the Alliance for Automobile Manufacturers oppose the inclusion of CTI. BMW and Honda opposed CTI because they believe that the increased stringency of CTI will lead to more aggressive air bags and/or softer vehicle structures, which would have a negative effect on real world benefits. Honda stated that the addition of CTI for the testing of the unbelted 50th percentile male dummy and other sized dummies requires a tremendous amount of development work that will dilute and delay the development of advanced air bags. Subaru states that the industry has no experience on the appropriateness of CTI and that new injury criteria may hinder the development of new technologies. Isuzu opposed CTI based on unknown correlation with real world injury data, unknown biomechanical integrity, and opposition against establishing US specific criteria. Mazda states that there is no evidence that CTI is a valid measure of thoracic injury.

The AAMA whose members are Ford, General Motors and DaimlerChrysler, opposed the inclusion of CTI. The AAMA has presented a different interpretation of the data and has questioned the inclusion of a few of the data points which may be outliers in the analyses. As an alternative to CTI, the AAMA proposed using chest acceleration, chest deflection, and chest deflection rate for all dummy sizes in out-of-position testing and in-position testing for a severity equal to or less than the 30 mph generic sled test currently specified in FMVSS No. 208 (Table A5.1). The chest acceleration limit proposed for the 50th percentile male is consistent with the current requirements of FMVSS No. 208. The chest deflection limits for the 50th percentile male is lower than that currently required. The deflection, acceleration, and deflection rate limits proposed for the other dummy sizes are scaled from the values for the 50th percentile male.

The Alliance of Automobile Manufacturers, which is the newly formed association whose members are BMW, DaimlerChrysler, Ford, General Motors, Mazda, Nissan, Toyota, Volkswagen, and Volvo supports further public comment on the comprehensive injury criteria recommended by AAMA and requires additional evaluation before the Alliance can endorse all the specific values in the AAMA submission.

Honda, Toyota, Volvo, Mazda, Autoliv, AIAM proposed to maintain the current criteria that limit chest acceleration and chest deflection independently for the 50th percentile male dummy and add similar criteria for the other dummy sizes. However, Toyota opposed the chest acceleration and chest deflection criteria for the 5th percentile female dummy, although Toyota offered no rationale for this opposition. Autoliv stated that the approach presented by CTI looks promising, but needs more evaluation.

Toyota and Volvo believe that since the maximum chest deflection and maximum chest acceleration do not occur simultaneously in a crash, the formulation for CIT should evaluate the combined loading at every instant in time, following the pattern used for Nij.

The Tri-Lateral Working Group, which is made up of major motor vehicle manufacturers from Europe, Japan and the United States who are members of ACEA, JAMA, and AAMA, expressed its concern about the application of new, untried test measures such as CTI and Nij. In addition, the combination of a multitude of tests, test variations, dummy positions, and new injury criteria presents an impossible task for manufacturers.

Honda, IIHS, Advocates for Highway Safety, Center for Auto Safety, Toyota, Takata, AIAM, Autoliv, and Alliance of Automobile Manufacturers recommend further research and review. Honda recommended further consideration by NHTSA of the regions of the surrogate data where chest acceleration is greater than 60 g and there is low deflections and regions where the chest deflection is greater than 75 mm and there are low accelerations. Honda suggests considering modifying the Hybrid III dummy in the future to be capable of measuring more than 75 mm of deflection. The IIHS urged NHTSA to continue its research to secure reasonable answers to some technical questions that were regarding CTI at the recent 42nd Stapp meeting. Advocates for Highway Safety supports more research and a public discussion of CTI before it is adopted. Advocates believes that other thoracic injury measures also have potential, and the existing chest injury criteria are well understood and well established even if their relative merits are subject to debate. Toyota states that CTI is not yet well established and is not ready for used in the development of vehicle safety systems nor for inclusion in a legal requirement.

Center for Auto Safety, Public Citizens supported the inclusion of CTI. Public Citizens states that CTI seems to be a more sophisticated and realistic means by which to measure chest injury.

Volkswagen commented that it did not have sufficient time to conduct testing with the various dummies and the proposed injury criteria. Volkswagen will submit comments on the proposed criteria when data and experience become available.

The National Transportation Safety Board (NTSB) suggests that is may be appropriate to use different CTI values for belted and unbelted occupants based on the comparison of actual NASS data to that predicted by CTI. Furthermore, the NTSB suggests that differences in the ribcage structure and organ position between adults and children may suggest the use of lower criteria for children.

Table A5.1: Chest Injury Criteria Proposed by AAMA and NPRM

Dummy	**Chest Deflection (mm)***		**Chest Deflection Rate (m/s)**		**Chest Acceleration (G)***	
	AAMA	**NPRM**	**AAMA**	**NPRM**	**AAMA**	**NPRM**
CRABI 12 Month	31	37	7.6	NA	50	40
HIII - 3 yr	36	42	8.0	NA	55	50
HIII - 6 yr	40	47	8.5	NA	60	60
HIII - Small Female	53	62	8.2	NA	73	60
HIII - Mid Male	64	76	8.2	NA	60	60

* For the NPRM, a linear combination of chest deflection and chest acceleration, CTI = 1, was imposed in addition to the above limits on chest deflection and chest acceleration.

Response to Comments:

Based on the comments received and the discussions at the two public meetings, the agency has opted to continue research on the thoracic injury criteria, CTI, and to propose a chest acceleration limit of 60 g's and a reduced chest deflection performance limit from the current 76 mm to 63 mm for the 50th percentile male dummy. However since CTI has demonstrated superior predictive capabilities than either deflection or acceleration alone, the agency proposes to use CTI to assess the probability of injury from dummy responses for both economic analyses and other safety evaluation efforts. The derivation of a modified CTI formulation, which includes suggestions by commenters to remove a few questionable data points and correct data reporting errors in a few tests, is discussed in detail in Chapter 4 of this report.

A.6 : Lower Extremity Injury Criteria

Currently, FMVSS 208 specifies an axial load limit of 10kN (2250 pounds) for the 50th percentile male Hybrid III dummy, as measured by a load cell at the location of the mid-shaft of the femur. The purpose of the axial load limit on the femur is to reduce the probability of fracture of the femur and also surrounding structures in the thigh, such as the patella and pelvis. The crash configuration currently specified in standard 208 is a frontal impact at speeds up to 30 mph and at an angle up to 30 degrees from the perpendicular with an unbelted or belted 50th percentile male dummy. Because the NPRM proposes to also require testing for the 5th percentile female in the same test configuration, it is appropriate to include an axial load limit for the 5th percentile female dummy. The axial load limit proposed in the NPRM was scaled down based on cross sectional area of the femur to 6.8 kN to account for the smaller bone size of the 5th percentile female.

Comments Received:

AAMA, Ford, and Autoliv support the inclusion of performance limits for femoral compressive loads for the 5th percentile female dummy specified in the NPRM in addition to maintaining the currently specified value for the 50th percentile male dummy. Furthermore, AAMA proposes adding femoral compressive load performance criteria of 2310 N for the 6 YO dummy.

The National Transportation Safety Board (NTSB) recommends that tolerance levels of lower extremities need to be further investigated and validated. NTSB also suggests that the NHTSA consider dummies such as advanced lower extremity (ALEX) dummy for future incorporation into the standards.

Response to Comments:

Although the NHTSA agrees with the AAMA that femoral compressive load limits for the six year-old dummy are important to consider, the NPRM does not specify such limits because the testing configurations specified in the NPRM for the six year-old dummy do not impose substantial loading on the lower extremities. For instance, NPRM positions 1 and 2 for the six year-old specify chest loading and neck loading positions associated with the deployment of the passenger’s side air bag at close proximity. The pre-impact breaking test specified in the NPRM with an unbelted six year-old dummy could result in loading to the femur, but there is a low risk of femoral injury at the specified speed of – kph. The NHTSA is continuing the development of an advanced lower extremity test device, the THOR-LX, and continues to sponsor experimental impact injury research to determine the mechanisms and tolerances of the lower extremities, including the foot, ankle and leg. When this effort is complete, it is anticipated that this research will be incorporated into future safety standards.

A.7: Real world problem/ Real world benefits of the proposed injury criteria

Comments Received:

A number of commenters (Nissan, Porsche, Toyota, Mazda) state that there has not been sufficient real world data to suggest that new injury criteria are needed. Nissan states that there has not been sufficient real world data to suggest that the existing chest and neck criteria are inappropriate, inadequate, or otherwise require improvement. Porsche states that there exists no evidence justifying an increase in the stringency of the thoracic injury criteria. Toyota believes that the real world accident data do not demonstrate a need for new injury criteria. Mazda states that CTI seems to be focused on improving the effectiveness of airbags in high speed crashes, an area where there is no demonstrated problem.

A number of commenters (Isuzu, Nissan, Mazda, BMW, AORC) question the real world benefits of adopting the new injury criteria, CTI and Nij. Isuzu states that the correlation of CTI and Nij with real world crash injury data is unknown. Nissan states that it has not been shown that the adoption of CTI or Nij will lead to the reduction of injuries in the real world. Nissan expressed it's concern about whether CTI is an appropriate injury measure for all test conditions. Mazda also states that NHTSA's own preliminary economic analysis suggests that there are at best, minimal benefits from the application of CTI.

BMW do not support adopting CTI or any other new injury criteria until the full effects of the criteria on real world occupant protection are well understood. The AORC believes each of the injury criteria must be shown to have a scientific foundation and that it must be shown that compliance with the criteria will in fact provide measurable safety benefits.

IIHS states that real-world crash data indicate that children are particularly at risk of serious and fatal neck injuries from deploying airbags.

Response to Comments:

Based on comments received, NHTSA has reconsidered its original proposal for using the CTI for regulatory purposes. Instead, it has opted to employ individual limits for chest acceleration (60g) and chest deflection (63 mm) for the 50th percentile male and scaled values for the various dummy sizes. However, the agency continues to propose to use the CTI to assess probability of injury from dummy responses for both its economic and other safety evaluation efforts. Details are presented in Chapter 4 along with efforts to link performance limits with real world problems.

A.8: Other Injury Criteria

NHTSA proposed injury criteria and performance limits for the head/brain, neck, chest (except the 12 month CRABI dummy), and femur (adult dummy only) for all dummy sizes. In addition to receiving comments on the proposed injury criteria, the agency received comments on comments on two areas of possible injury associated with air bags which are not specified in the NPRM.

Comments Received:

> The Center for Automobile Safety expressed concern that the NPRM did not proposed injury criteria for the upper extremities. The Center stated that although a broken arm or hand may not be as traumatic as a severed spinal cord or a cardiac failures, these types of injuries still pose a hazzard to drivers who are the intended beneficiaries of air bag deployment.
>
> The American Academy of Otolaryngology and Head and Neck Surgery, Inc. states that there have been 60 documented cases of patients as of December 15, 1998, seeking medical assistance because of hearing loss, tinnitus, and/or vertigo after exposure to airbag deployment. Out of 51 patients who underwent objective hearing evaluations, 43 showed evidence of hearing loss, 42 experienced tinnitus, 13 complained of dizziness, and 6 patients sustained ruptured ear drums, four of whom required surgery. The Academy states that these reports are in contrast to previous statements by NHTSA and others denying the potential for injury to occur after exposure to air bag deployment. The Academy wishes to balance the benefits of air bags with risks of noise exposure and permanent hearing loss during air bag deployment, particularly during non-threatening crashes.
>
> The American Academy of Pediatrics recommends testing of pregnant dummy and assessment of fetal injury.
>
> *Response to Comments:*
> The agency acknowledges that drivers' side air bags may pose a risk to the upper extremities and fully supports the efforts of the SAE to develop an instrumented arm the approximate size and weight of the arm of a 5th percentile female. This instrumented arm will allow manufacturers to measure the forces, moments, rotations and accelerations of the arm and to minimize the potential for upper extremity injury. Preliminary research sponsored by the NHTSA has provided provisional injury criteria performance limits for the bending strength of the forearm (Bass, Stapp 1997) and research by others have provided provisional limits based on the acceleration of the wrist (Hardy, Stapp 1997). Since the agency's primary focus of the rulemaking is to eliminate the serious risks associated with the deployment of air bags, at the present time the agency will not be proposing injury criteria for the upper extremities. However, the agency will continue to monitor the incidence and severity of upper extremity injuries.

The agency is aware of the possible risks of hearing loss and tinnitus following exposure to air bag deployments and is conducting research in this area. Since the agency's primary focus of the rulemaking is to eliminate the serious risks associated with the deployment of air bags, at the present time the agency will not be proposing injury criteria associated with the noise of the deploying air bag. However, the agency will continue to monitor the incidence and severity of hearing loss and tinnitus.

A.9: Scaling

NHTSA is proposing injury criteria and performance limits that it believes are appropriate for each sized dummy. The limits were scaled based on the limited existing biomechanical data for the various sizes to maintain a regulation with a consistent level of protection for all occupants. The agency requested comments on what risk levels are acceptable, what factors should be considered in selecting performance limits for different test requirements, and how uncertainties related to injury criteria should be addressed, especially with respect to children.

Comments Received:

> A few commenters (NTSB, AAMA, Honda) stated that the scaling procedures proposed in the NPRM needed modifications. The National Transportation Safety Board states that the scaling procedures used in developing the performance limits for the various dummies seems overly simplistic and potentially inappropriate. However, the NTSB did not provide an alternative procedure for scaling. The AAMA provided an alternative set of scaling techniques, which are discussed in the appropriate chapters of this document. Honda stated that additional scientific debate and further biomechanical testing is needed to improve scaling techniques before implementing them as new requirements.
>
> A number of commenters (Trauma Link, Advocates for Highway Safety) suggested that due to increased susceptibility to injury and uncertainties in the development of injury criteria for children, the performance limits should be more conservative for children. Trauma Link stated that children experience significantly different injuries and injury constellations than adults (e.g. more brain swelling), additional funding for research on pediatric mechanical properties and injury tolerances is needed. Trauma Link suggests that the proposed criteria should be considered as interim criteria that should be re-evaluated and updated on a regular basis. Advocates for Highway Safety supports separate, scaled injury criteria performance limits for the various dummy sizes based on the view that children are susceptible to injury at lower level impacts than adults. Advocates believes that for any area of uncertainty, performance limits should be set in favor or assuring greater protection for infants and children. Thus, Advocates believes that maintaining the same level of the risk of injury for children and for adults is not an appropriate policy.
>
> *Response to Comments:*
>
> Based on the comments received and discussions at the public meetings, the agency has adopted more stringent scaling techniques for the injury criteria performance limits for the child dummies, as discussed in detail in section 1-2.

Appendix B

Tabulated Results from Analyses of Available NHTSA Test Data

The injury measures for each body region were calculated and compared for a wide variety of tests available in the NHTSA database. Analyses were conducted for data from 30 mph FMVSS No. 208 compliance tests, 35 mph NCAP tests, 48 kmph rigid barrier and 40 kmph offset deformable barrier tests with 5th percentile female dummies, and out-of-position tests with the 6-year old and 5th percentile female dummies. The test data are listed in the following tables according to the test type and the occupant position (driver or front seat passenger).

For the head region, HIC_{15} injury criteria proposed in this SNPRM and HIC_{36} proposed in the NPRM (Docket 98 4405-9) are listed for each test. For the neck, the maximum SNPRM Nij (proposed in this SNPRM) and the maximum NPRM Nij (proposed in the NPRM NHTSA Docket 1998-4405-9) are listed. Also listed for the neck region are the maximum tension, compression and shear forces in Newtons and the maximum extension and flexion moments in Newton-meters. For the chest region, the maximum chest deflection in millimeters, the 3-msec clip value of resultant chest acceleration in g's, maximum chest velocity in m/s, and CTI-V2 (Version of CTI presented in this SNPRM: Equation 4.2 and Table 4-5) are listed. For the lower extremities, the maximum right and left femur force in Newtons are listed, where applicable.

The performance limits for the injury measures corresponding to the ATD under consideration are presented above each column. The performance limits for HIC15, SNPRM Nij, chest acceleration, chest compression, and femur force for different dummy sizes are those recommended in this SNPRM for regulation purpose and are listed in Table 6-1. The performance limit for HIC36 and NPRM Nij for different dummy sizes are as presented in NPRM NHTSA Docket 1998-4405-9. Although CTI-V2 has not been recommended for regulation purpose in this SNPRM, it is used as a comparison to the individual chest deflection and chest acceleration performance limits for analysis purposes. The individual performance limits for maximum neck tension, compression, flexion, and extension for the 50th percentile male are from the current FMVSS No. 208 neck injury performance limits using the alternative sled test, while those for other dummy sizes are from AAMA recommendations for out-of-position occupants.

A vehicle is said to pass a certain injury measure if the performance limit for the injury measure is greater or equal to the maximum computed value of the injury measure. In each table, summary statistics are presented for each injury measure such as average value of the injury measure, number of vehicles in table with computed injury measures, the number of vehicles that pass the injury measure performance limit, and the percentage passing rate of the vehicles for that injury measure. The summary statistics are used to compare the performance of the different injury measures for each body region.

Table B.1 1994 - 1996 NCAP Tests - Belted 50th Percentile Male ATD In Driver Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2053	VOLVO	850	1994	235	435	NA	NA	NA	NA	NA	NA	NA	NA	43	NA	NA	NA	6243	6099
2034	TOYOTA	COROLLA	1994	217	383	-406	275	-18	12	-449	1852	0.44	0.530	54	NA	NA	NA	NA	NA
2158	SUBARU	LEGACY	1995	261	482	-143	380	-21	18	-1816	450	0.46	0.546	46	32	NA	0.82	864	4490
2160	SATURN	SL1	1995	392	633	-395	853	-78	42	-2013	813	0.99	1.105	45	39	NA	0.88	NA	3191
2126	NISSAN	MAXIMA	1995	552	747	-346	464	-33	23	-2251	678	0.51	0.635	50	30	NA	0.85	1890	3433
2130	FORD	WINDSTAR	1995	325	517	-215	394	-44	25	-1321	315	0.63	0.704	42	31	NA	0.77	5000	3180
2211	FORD	EXPLORER	1995	386	525	-179	320	-30	15	-278	2294	0.69	0.814	48	33	1.60	0.85	4375	5008
2154	FORD	CONTOUR	1995	265	471	-796	574	-39	45	-215	1501	0.44	0.489	42	43	2.53	0.89	3190	4908
2222	CHEVROLET	LUMINA	1995	243	395	-190	200	-6	25	-265	1984	0.51	0.601	42	32	1.37	0.78	4688	3086
2313	ISUZU	RODEO	1995	366	528	-245	584	-46	48	-2270	352	0.51	0.635	57	43	2.73	1.06	NA	NA
2297	NISSAN	ALTIMA	1995	432	710	-541	377	-53	28	-2077	240	0.81	0.919	51	31	2.16	0.86	NA	NA
2298	NISSAN	SENTRA	1995	399	584	-273	489	-38	35	-1867	214	0.63	0.734	51	36	2.04	0.92	NA	NA
2312	FORD	TAURUS	1996	329	541	-564	232	-18	22	-231	1733	0.42	0.51	44	33	1.64	0.80	3313	4819
2319	AUDI	A4	1996	491	665	-416	328	-32	23	-534	1807	0.45	0.54	45	38	2.18	0.87	5185	NA
2320	DODGE	NEON	1996	400	610	-739	97	-10	62	-517	2060	0.62	0.68	54	40	2.06	0.99	5982	6859
2335	DODGE	GRAND CARAVAN	1996	663	879	-176	280	-30	13	-1706	421	0.48	0.54	54	42	2.66	1.00	5054	4596
2336	DODGE	RAM 250 VAN	1996	787	874	-506	1009	-83	57	-270	4803	1.42	1.65	55	33	2.50	0.94	11663	8577
2341	PONTIAC	GRAND AM	1996	421	535	-622	658	-13	50	-42	2036	0.59	0.67	48	32	1.67	0.85	5596	3186
2342	LEXUS	ES300	1996	293	432	-426	140	-11	38	-199	1412	0.42	0.47	43	28	1.52	0.75	3251	2575
2343	LANDROVER	DISCOVERY	1996	592	825	-208	822	-56	45	-1031	2837	0.80	0.96	54	35	2.20	0.94	5879	4695
2359	CADILLAC	DE VILLE	1996	735	1004	-851	227	-89	30	-1677	2536	1.09	1.18	56	35	2.18	0.96	6279	4923
2360	FORD	MUSTANG	1996	113	216	-109	378	-35	42	-653	1637	0.52	0.60	45	42	1.45	0.90	4893	5318
2367	MERCURY	VILLAGER	1996	243	405	-155	584	-19	47	-2076	1108	0.54	0.63	47	32	1.70	0.83	5073	4914
2368	FORD	CROWN VICTORIA	1996	279	499	-391	268	-14	16	-1912	933	0.47	0.56	37	31	1.23	0.71	4562	2857
2370	MAZDA	MX5	1996	400	710	-352	365	-48	19	-2770	1203	0.95	1.10	54	32	1.70	0.91	6509	4092
2371	HONDA	CIVIC	1996	329	480	-302	426	-12	41	-2797	1175	0.63	0.78	46	35	1.43	0.86	4356	3618
2372	MITSUBISHI	MIRAGE	1996	350	516	-323	864	-40	20	-438	2471	0.86	1.00	58	61	2.61	1.24	4603	4439
2373	SUBARU	IMPREZA	1996	226	491	-123	260	-22	28	-942	1798	0.44	0.53	51	33	1.98	0.89	2981	1834
2376	GEO	TRACKER	1996	653	930	-482	205	-40	39	-2623	1371	0.74	0.88	64	43	2.23	1.13	5883	5907
2398	HYUNDAI	ELANTRA	1996	323	528	-443	413	-22	43	-128	1920	0.51	0.60	58	35	2.14	0.98	4805	5543
2404	CHEVROLET	ASTRO	1996	362	613	-101	688	-21	63	-188	1684	0.57	0.62	61	37	2.75	1.03	6603	8727
2405	ACURA	2.5 TL	1996	536	740	-519	384	-22	55	-79	1712	0.53	0.59	48	53	2.38	1.05	5922	5526
2407	CHEVROLET	C-1500	1996	292	498	-279	282	-16	30	-260	2486	0.57	0.71	39	40	1.83	0.82	4814	7136
2409	TOYOTA	4RUNNER	1996	537	920	-582	438	-36	40	-1082	2670	0.73	0.86	56	42	2.93	1.03	5003	5132
2413	ISUZU	TROOPER II	1996	441	668	-345	685	-31	49	-853	2724	0.72	0.87	56	44	2.63	1.06	4659	6110
2414	NISSAN	PICKUP	1996	480	758	-271	544	-26	45	-343	3040	0.77	0.91	68	49	3.51	1.24	2925	2940
2427	MAZDA	MPV	1996	350	593	-165	268	-19	18	-343	2121	0.49	0.61	46	32	1.49	0.83	3170	4041
2428	HONDA	CIVIC	1996	232	375	-470	133	-18	39	-292	1771	0.48	0.55	46	33	1.44	0.82	5127	2243
2429	LINCOLN	TOWN CAR	1996	316	600	-302	215	-30	12	-684	2312	0.66	0.77	44	19	1.40	0.68	3768	2188
2430	JEEP	GRAND CHEROKEE	1996	679	952	-389	911	-58	2	-455	3634	1.04	1.22	59	41	2.49	1.05	6119	5352
2453	DODGE	CARAVAN	1996	528	773	-500	753	-30	73	-357	2400	0.73	0.80	51	27	1.36	0.83	7193	5624
2456	NISSAN	PATHFINDER	1996	880	1107	-293	835	-25	43	-428	3478	0.88	1.05	51	23	1.16	0.79	2433	4929
2457	FORD	RANGER	1996	413	724	-117	253	-37	53	-293	2237	0.76	0.88	53	46	1.74	1.04	5715	6434
2458	CHRYSLER	SEBRING CONVERTIB	1996	416	654	-358	1042	-36	83	-1032	1585	0.58	0.61	50	30	1.28	0.85	4297	6838
2459	TOYOTA	PASEO	1996	385	632	NA	NA	-19	13	-1996	1162	0.58	0.69	48	31	1.18	0.84	2395	3886
	Average			*439*	*659*	*-371*	*468*	*-31*	*38*	*-886*	*2069*	*0.67*	*0.78*	*51*	*37*	*1.96*	*0.92*	*5031*	*4871*
	Pass			*30*	*31*			*30*	*33*	*33*	*30*	*30*	*28*	*30*	*33*		*23*	*32*	*32*
	Total Vehicles			*33*	*33*			*33*	*33*	*33*	*33*	*33*	*33*	*33*	*33*		*33*	*33*	*32*
	Pass Rate			*91%*	*94%*			*91%*	*100%*	*100%*	*91%*	*91%*	*85%*	*91%*	*100%*		*70%*	*97%*	*100%*

Table B.2

1994 - 1996 NCAP Tests - Belted 50th Percentile Male ATD In Passenger Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2053	VOLVO	850	1994	212	422	-764	415	-21	47	-661	1286	0.41	NA	58	NA	NA	NA	4863	4201
2034	TOYOTA	COROLLA	1994	276	433	-545	368	19	55	-365	1124	0.40	0.530	NA	NA	NA	NA	NA	NA
2158	SUBARU	LEGACY	1995	314	532	-208	499	-20	38	-1962	565	0.52	0.546	51	36	NA	0.92	1333	1982
2160	SATURN	SL1	1995	308	506	-589	500	-60	29	-2267	1807	0.83	1.105	47	33	NA	0.84	4577	3658
2126	NISSAN	MAXIMA	1995	566	783	-129	816	-28	24	-2541	332	0.63	0.635	57	39	NA	1.01	3793	1296
2130	FORD	WINDSTAR	1995	117	230	-104	772	-21	59	-2165	420	0.66	0.704	41	34	NA	0.79	2533	3798
2211	FORD	EXPLORER	1995	233	448	-568	656	-30	60	-281	1943	0.51	0.814	48	41	2.97	0.93	3476	4572
2154	FORD	CONTOUR	1995	208	357	-388	158	-18	26	-133	1742	0.45	0.489	58	34	2.27	0.97	6490	4572
2222	CHEVROLET	LUMINA	1995	422	560	-434	412	-31	36	-255	2213	0.50	0.601	46	31	1.85	0.81	3600	2235
2313	ISUZU	RODEO	1995	539	782	-418	417	-35	38	-2299	286	0.76	0.635	59	51	2.64	1.15	NA	NA
2297	NISSAN	ALTIMA	1995	489	777	-78	449	-20	20	-2087	348	0.54	0.919	52	33	1.94	0.90	NA	NA
2298	NISSAN	SENTRA	1995	341	599	-42	709	-36	26	-1937	80	0.46	0.734	50	41	1.71	0.95	NA	NA
2312	FORD	TAURUS	1996	223	438	-684	351	-25	47	N/A	N/A	N/A	N/A	46	30	1.93	0.81	4580	3583
2319	AUDI	A4	1996	250	432	-56	449	-21	44	-265	1470	0.36	0.42	42	33	1.74	0.79	5378	5052
2320	DODGE	NEON	1996	350	531	-228	377	-20	39	-173	2383	0.55	0.68	54	36	2.91	0.94	6097	5308
2335	DODGE	GRAND CARAVAN	1996	257	403	-862	81	-12	76	-68	349	0.28	0.22	46	38	2.69	0.88	6339	6700
2336	DODGE	RAM 250 VAN	1996	342	764	-514	2097	-60	148	-1089	2510	0.79	0.78	51	35	1.49	0.90	2180	2042
2341	PONTIAC	GRAND AM	1996	441	604	-936	315	-18	109	-306	1631	0.60	0.60	49	27	5.81	0.81	9136	5445
2342	LEXUS	ES300	1996	683	902	-618	169	-34	21	-555	1095	0.37	0.43	49	29	1.98	0.83	3956	4247
2343	LANDROVER	DISCOVERY	1996	222	379	-152	2153	-97	38	-390	2969	1.44	1.60	63	46	3.60	1.15	4492	4129
2359	CADILLAC	DE VILLE	1996	860	1236	-400	331	-50	10	-1196	2704	0.72	0.87	60	52	2.68	1.16	3730	3844
2360	FORD	MUSTANG	1996	121	128	-365	926	-50	79	-2463	1444	0.90	1.03	43	31	2.33	0.77	5601	3249
2367	MERCURY	VILLAGER	1996	521	861	-166	749	-38	25	-3165	951	0.74	0.90	51	39	2.60	0.94	7253	3638
2368	FORD	CROWN VICTORIA	1996	112	218	-586	645	-39	24	N/A	N/A	N/A	N/A	42	25	1.52	0.71	3518	3197
2370	MAZDA	MX5	1996	452	672	-160	574	-33	48	-2029	608	0.57	0.64	58	29	1.67	0.93	6676	8067
2371	HONDA	CIVIC	1996	178	329	-1097	414	-13	68	-925	1086	0.32	0.35	45	31	1.74	0.81	2382	2561
2372	MITSUBISHI	MIRAGE	1996	802	997	-6095	8907	-56	241	-1625	606	0.87	0.90	54	40	2.37	0.98	3949	4237
2373	SUBARU	IMPREZA	1996	270	515	-181	315	-28	21	-924	1789	0.57	0.66	54	41	2.91	1.00	3741	2541
2376	GEO	TRACKER	1996	489	666	-849	66	-41	45	-2157	684	0.80	0.92	62	44	2.22	1.12	3174	7018
2398	HYUNDAI	ELANTRA	1996	517	773	-417	265	-32	27	-362	1738	0.47	0.55	62	50	3.77	1.17	6917	7328
2404	CHEVROLET	ASTRO	1996	218	412	-1498	502	-139	30	-828	2777	1.55	1.67	69	34	2.95	1.09	6033	3520
2405	ACURA	2.5 TL	1996	374	628	-396	702	-32	66	-749	1223	0.48	0.49	49	40	2.07	0.93	2313	2621
2407	CHEVROLET	C-1500	1996	320	487	-98	1481	-27	103	-885	2266	0.60	0.70	36	40	1.96	0.78	2522	2152
2409	TOYOTA	4RUNNER	1996	390	601	-606	533	-44	40	-479	2152	0.57	0.67	62	42	3.02	1.09	3880	4281
2413	ISUZU	TROOPER II	1996	521	843	-626	660	-35	33	-598	2238	0.55	0.66	61	41	2.94	1.08	6235	6111
2414	NISSAN	PICKUP	1996	322	653	-2031	345	-56	88	-1119	2457	0.93	1.06	55	48	2.24	1.08	1233	1291
2427	MAZDA	MPV	1996	242	409	-352	360	-26	48	-414	1851	0.50	0.58	46	38	1.83	0.87	4402	5164
2428	HONDA	CIVIC	1996	379	531	-388	867	-67	21	-610	1268	0.76	0.82	45	31	2.64	0.80	5949	5085
2429	LINCOLN	TOWN CAR	1996	86	181	-776	212	-73	32	-531	1716	0.69	0.72	43	24	1.72	0.71	3768	2188
2430	JEEP	GRAND CHEROKEE	1996	355	554	-1196	304	-18	99	-587	1591	0.55	0.53	57	41	4.23	1.03	6482	4804
2453	DODGE	CARAVAN	1996	237	419	-383	837	-20	133	-756	1404	0.48	0.52	45	19	1.25	0.68	4608	3535
2456	NISSAN	PATHFINDER	1996	568	797	-107	914	-34	35	-351	3374	0.90	1.08	57	23	1.07	0.85	3140	3624
2457	FORD	RANGER	1996	446	711	-305	846	-34	64	-718	2393	0.70	0.81	53	46	2.68	1.04	4413	5890
2458	CHRYSLER	SEBRING CONVERTIB	1996	656	698	-548	583	-66	46	-523	2500	0.96	1.09	54	28	1.43	0.87	5831	3469
2459	TOYOTA	PASEO	1996	406	655	-752	253	-58	23	-2009	329	0.53	0.64	53	47	1.40	1.05	4749	3858
	Average			***382***	***589***	***-740***	***866***	***-42***	***60***	***-931***	***1728***	***0.68***	***0.76***	***52***	***36***	***2.41***	***0.93***	***4687***	***4236***
	Pass			***31***	***32***			***26***	***32***	***31***	***30***	***29***	***25***	***27***	***33***		***22***	***33***	***33***
	Total Vehicles			***33***	***33***			***33***	***33***	***31***	***31***	***31***	***31***	***33***	***33***		***33***	***33***	***33***
	Pass Rate			***94%***	***97%***			***79%***	***97%***	***100%***	***97%***	***94%***	***81%***	***82%***	***100%***		***67%***	***100%***	***100%***

Table B.3 1997 NCAP Tests - Belted 50th Percentile Male ATD In Driver Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2452	FORD	F150 PICKUP	1997	291	548	-138	333	-45	24	-959	2096	0.51	0.61	53	21	0.99	0.80	7961	5636
2454	PONTIAC	GRAND PRIX	1997	578	719	-366	369	-17	38	-228	2058	0.56	0.65	53	21	1.07	0.79	5690	3447
2455	JEEP	WRANGLER	1997	347	566	-410	256	-55	12	-131	2681	0.92	1.03	43	24	1.56	0.71	5558	4596
2460	PONTIAC	GRAND AM	1997	455	626	NA	NA	NA	NA	NA	NA	NA	NA	45	19	1.27	0.68	3630	2327
2461	MITSUBISHI	GALANT	1997	349	526	NA	NA	NA	NA	NA	NA	NA	NA	54	41	1.95	1.00	4043	6925
2464	FORD	ESCORT	1997	624	959	NA	NA	NA	NA	NA	NA	NA	NA	58	42	2.30	1.05	2333	6985
2465	CADILLAC	DE VILLE	1997	439	656	-135	535	-24	23	-2264	507	0.60	0.71	45	37	1.65	0.86	4320	5398
2466	CHEVROLET	S-10	1997	716	955	-864	575	-31	47	-4114	1270	0.92	1.15	53	27	1.57	0.85	4006	7485
2475	HONDA	ACCORD	1997	296	447	NA	NA	NA	NA	NA	NA	NA	NA	51	37	1.70	0.92	4043	6925
2476	FORD	CLUBWAGON MPV	1997	632	932	-602	336	-42	41	-703	1795	0.52	0.58	48	42	2.11	0.94	3447	2239
2478	CHEVROLET	BLAZER	1997	298	595	-645	1029	-80	37	-1189	3186	1.18	1.34	57	27	1.48	0.89	3871	7004
2487	VOLVO	960	1997	316	511	-517	306	-27	36	-790	1582	0.46	0.52	45	25	1.26	0.73	3082	1284
2488	FORD	EXPEDITION	1997	440	693	-341	740	-30	29	-1999	686	0.56	0.67	42	30	1.40	0.76	3995	5024
2492	PONTIAC	GRAND AM	1997	358	517	-349	747	-18	27	-175	1573	0.38	0.46	41	25	1.07	0.69	3038	4410
2496	TOYOTA	RAV4	1997	594	919	-474	165	-22	27	-785	2580	0.64	0.78	51	39	3.58	0.95	2761	4763
2527	HYUNDAI	ACCENT	1997	687	918	-507	345	-40	20	-1808	260	0.53	0.61	59	37	2.02	1.00	3938	4328
2528	CHEVROLET	CAVALIER	1997	468	646	-257	1225	-48	32	-1486	425	0.65	0.72	50	27	1.47	0.82	3225	4267
2529	CHEVROLET	MALIBU	1997	550	810	-424	1235	-58	55	-1942	1017	0.82	0.93	44	33	2.21	0.81	3178	4070
2530	DODGE	RAM	1997	538	793	-319	666	-27	37	-2058	843	0.66	0.77	48	34	1.26	0.86	1300	4744
2531	TOYOTA	CAMRY	1997	469	625	-643	336	-10	78	-91	1827	0.62	0.65	69	20	1.14	0.96	5671	2744
2540	CHEVROLET	TAHOE	1997	516	833	-293	290	-40	23	-1002	2245	0.62	0.74	45	45	2.58	0.93	8605	5162
2542	TOYOTA	TACOMA	1997	1099	1411	-232	355	-40	12	-886	3453	0.80	0.99	68	39	2.51	1.14	5410	1933
2548	CHEVROLET	K1500 PICKUP	1997	193	314	-581	470	-9	39	-212	1978	0.52	0.60	37	21	1.10	0.62	7133	7568
2549	CHEVROLET	PICKUP	1997	240	467	-914	415	-48	36	-1618	1426	0.72	0.81	40	23	2.23	0.67	5612	5531
2550	DODGE	DAKOTA	1997	397	668	-587	406	-33	32	-654	2630	0.61	0.75	52	14	0.92	0.72	5765	3613
2551	BUICK	LESABRE	1997	370	565	-572	243	-30	29	-409	1813	0.46	0.54	44	19	0.91	0.67	3501	5056
2552	CHEVROLET	VENTURE	1997	465	692	-331	339	-50	14	-711	3033	0.72	0.88	49	17	0.94	0.71	6005	7536
2556	JEEP	CHEROKEE	1997	399	692	-124	714	-35	19	-390	3090	0.95	1.12	61	39	3.28	1.05	6644	8666
2637	KIA	SPORTAGE	1997	602	969	-117	825	-41	20	-496	3611	0.82	1.02	49	47	2.67	1.00	5299	4473
2638	KIA	SEPHIA	1997	619	872	-1035	249	-23	56	-427	2092	0.63	0.70	45	33	1.90	0.82	7726	4537
2639	DODGE	NEON	1997	577	850	-853	192	-16	58	-444	2251	0.67	0.75	60	NA	1.20	NA	5710	6327
2640	NISSAN	200 SX	1997	238	415	-198	565	-22	43	-155	1802	0.44	0.51	43	28	NA	0.75	3654	2201
2642	MITSUBISHI	MONTERO	1997	378	641	-104	532	-51	46	-1244	2624	0.82	0.94	56	26	1.29	0.87	4691	4789
2754	CHEVROLET	CAVALIER	1997	373	530	-1015	111	-16	24	-197	1575	0.35	0.44	48	29	1.50	0.82	4373	5407
2755	TOYOTA	TERCEL	1997	281	476	-220	249	-28	14	-446	2225	0.59	0.71	51	29	1.67	0.85	2502	2181
2898	GMC	EV1	1997	517	749	-1314	216	-20	79	-344	1252	0.44	0.45	54	32	1.60	0.90	3004	3310
	Average			***464***	***697***	***-484***	***480***	***-34***	***35***	***-949***	***1921***	***0.65***	***0.75***	***50***	***30***	***1.70***	***0.85***	***4576***	***4803***
	Pass			***34***	***35***			***30***	***32***	***31***	***30***	***31***	***27***	***32***	***35***		***31***	***36***	***36***
	Total Vehicles			***36***	***36***			***32***	***32***	***32***	***32***	***32***	***32***	***36***	***35***		***35***	***36***	***36***
	Pass Rate			***94%***	***97%***			***94%***	***100%***	***97%***	***94%***	***97%***	***84%***	***89%***	***100%***		***89%***	***100%***	***100%***

Table B.4 1997 NCAP Tests - Belted 50th Percentile Male ATD In Passenger Postion

tstno	make	model	year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2452	FORD	F150 PICKUP	1997	304	474	-199	930	-37	41	-516	2101	0.56	0.66	42	21	0.97	0.67	4693	3796
2454	PONTIAC	GRAND PRIX	1997	374	529	NA	NA	NA	NA	NA	NA	NA	NA	49	12	0.71	0.67	4670	3719
2455	JEEP	WRANGLER	1997	316	487	NA	NA	NA	NA	NA	NA	NA	NA	57	16	1.34	0.78	3955	3471
2460	PONTIAC	GRAND AM	1997	189	372	NA	NA	NA	NA	NA	NA	NA	NA	42	23	2.98	0.70	5118	4703
2461	MITSUBISHI	GALANT	1997	295	487	-643	888	-72	15	-1499	340	0.87	0.96	50	40	2.42	0.94	4038	4069
2464	FORD	ESCORT	1997	263	436	-935	113	-48	60	-2320	400	0.66	0.75	56	39	2.35	0.99	5115	4405
2465	CADILLAC	DE VILLE	1997	404	552	-553	426	-49	17	-2007	263	0.51	0.62	53	38	2.21	0.96	4399	3675
2466	CHEVROLET	S-10	1997	1205	1205	-621	445	-45	37	-1602	1238	0.59	0.65	43	33	1.52	0.80	3586	2703
2475	HONDA	ACCORD	1997	499	713	-616	164	-25	26	-1767	430	0.53	0.63	47	34	1.50	0.85	2872	1255
2476	FORD	CLUBWAGON MPV	1997	359	565	-154	859	-38	42	-231	2110	0.70	0.80	50	45	2.82	0.98	4415	3980
2478	CHEVROLET	BLAZER	1997	833	1525	-833	1605	-44	98	-2702	3011	0.83	0.97	49	44	2.07	0.97	1048	2598
2487	VOLVO	960	1997	511	698	-292	254	-30	27	-1637	1006	0.42	0.49	53	22	1.00	0.80	3779	4087
2488	FORD	EXPEDITION	1997	212	393	-618	67	-49	21	-1804	203	0.45	0.53	43	35	2.20	0.81	4469	3462
2492	PONTIAC	GRAND AM	1997	425	617	-337	526	-54	13	-1060	1657	0.72	0.79	45	33	1.07	0.82	4228	4202
2496	TOYOTA	RAV4	1997	610	743	-912	326	-29	58	-468	1402	0.47	0.51	57	42	3.59	1.04	3922	3351
2527	HYUNDAI	ACCENT	1997	142	252	-864	363	-72	30	-1379	316	0.64	0.68	49	36	2.80	0.89	3192	3394
2528	CHEVROLET	CAVALIER	1997	600	885	-473	923	-38	26	-1664	567	0.51	0.58	45	29	1.80	0.78	3944	4207
2529	CHEVROLET	MALIBU	1997	305	546	-455	417	-36	21	-1739	407	0.45	0.54	44	33	1.75	0.81	4402	1899
2530	DODGE	RAM	1997	640	1004	-361	987	-16	12	-1093	125	0.35	0.40	54	40	1.50	0.99	1562	693
2531	TOYOTA	CAMRY	1997	225	501	-357	473	-25	25	-1823	367	0.56	0.65	49	17	1.14	0.71	2868	2031
2540	CHEVROLET	TAHOE	1997	308	545	-97	915	-38	73	-660	2266	0.72	0.83	45	40	1.88	0.89	1634	3756
2542	TOYOTA	TACOMA	1997	458	962	-206	1742	-67	151	-1078	2723	0.76	0.84	50	56	2.26	1.09	3222	3882
2548	CHEVROLET	K1500 PICKUP	1997	261	381	-830	368	-73	48	-2174	1105	0.62	0.65	49	21	1.60	0.75	3588	4174
2549	CHEVROLET	PICKUP	1997	448	688	-754	581	-49	40	-1666	1376	0.48	0.55	39	22	0.90	0.64	796	2987
2550	DODGE	DAKOTA	1997	393	602	-1149	586	-80	35	-1751	585	0.70	0.73	58	19	1.59	0.83	4583	1504
2551	BUICK	LESABRE	1997	448	686	-283	612	-45	32	-1477	399	0.68	0.77	47	18	0.81	0.69	5131	3083
2552	CHEVROLET	VENTURE	1997	515	704	-416	851	-71	31	-2163	409	1.05	1.17	49	17	2.79	0.71	4235	4606
2556	JEEP	CHEROKEE	1997	303	512	-382	501	-31	39	-531	1927	0.66	0.77	63	40	2.36	1.09	6459	5707
2637	KIA	SPORTAGE	1997	454	1039	-326	2248	-57	142	-828	2597	0.90	0.91	54	51	2.85	1.10	4640	3729
2638	KIA	SEPHIA	1997	267	387	-154	1505	-86	34	-306	2521	1.17	1.29	52	32	3.02	0.89	8128	7302
2639	DODGE	NEON	1997	678	815	-260	533	-25	23	-248	3086	0.82	0.98	72	NA	0.51	NA	8024	6440
2640	NISSAN	200 SX	1997	392	577	-204	618	-33	51	-439	1927	0.45	0.54	49	35	NA	0.88	2805	2392
2642	MITSUBISHI	MONTERO	1997	497	680	-599	271	-61	46	-3016	2113	0.76	0.93	55	24	6.90	0.85	5600	4652
2754	CHEVROLET	CAVALIER	1997	520	747	-825	386	-16	63	-131	1436	0.47	0.49	53	34	2.02	0.92	4470	3231
2755	TOYOTA	TERCEL	1997	424	576	-137	349	-25	33	-415	1861	0.45	0.55	54	39	2.20	0.98	4116	4554
2898	GMC	EV1	1997	755	1085	-516	249	-38	14	-298	1696	0.47	0.54	56	38	2.50	0.99	2426	2872
	Average			***440***	***666***	***-496***	***669***	***-45***	***43***	***-1288***	***1332***	***0.63***	***0.72***	***51***	***32***	***2.06***	***0.86***	***4059***	***3627***
	Pass			***33***	***31***			***25***	***33***	***33***	***33***	***31***	***31***	***34***	***35***		***31***	***36***	***36***
	Total Vehicles			***36***	***36***			***33***	***33***	***33***	***33***	***33***	***33***	***36***	***35***		***35***	***36***	***36***
	Pass Rate			***92%***	***86%***			***76%***	***100%***	***100%***	***100%***	***94%***	***94%***	***94%***	***100%***		***89%***	***100%***	***100%***

Table B.5

1998 NCAP Tests - Belted 50th Percentile Male ATD In Driver Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2643	FORD	WINDSTAR	1998	190	363	-436	202	-4	52	-42	1352	0.44	0.48	42	17	0.81	0.63	3949	2382
2676	DODGE	STRATUS	1998	716	872	-392	1114	-22	100	-1378	1890	0.68	0.71	54	39	2.25	0.98	5721	4821
2683	DODGE	CARAVAN	1998	680	870	-352	225	-47	4	-536	2611	0.90	1.04	53	50	2.15	1.07	5318	4290
2684	FORD	RANGER	1998	279	441	-338	278	-32	30	-654	2045	0.53	0.64	51	42	1.61	0.97	4638	6015
2688	CHEVROLET	CAVALIER	1998	436	643	-221	1053	-18	64	-85	1671	0.50	0.58	57	27	1.81	0.90	4675	6130
2689	CHEVROLET	CAVALIER	1998	360	514	-406	840	-38	36	-407	2112	0.59	0.68	54	36	1.97	0.95	4376	6445
2691	FORD	WINDSTAR	1998	234	353	-397	619	-23	54	-241	993	0.35	0.36	37	26	1.56	0.66	6239	3065
2708	FORD	CONTOUR	1998	298	514	-339	316	-11	55	-179	1974	0.54	0.61	42	42	2.79	0.87	4680	2869
2709	DODGE	NEON	1998	475	655	-253	979	-19	98	-405	1905	0.64	0.69	57	39	2.18	1.00	5305	5351
2710	TOYOTA	CAMRY	1998	342	525	-272	606	-45	14	-1259	77	0.57	0.63	46	31	1.44	0.81	2342	4246
2711	DODGE	GRAND CARAVAN	1998	883	1026	-245	416	-34	27	-2676	211	0.61	0.75	54	46	3.33	1.05	5115	6304
2712	HONDA	ACCORD	1998	473	631	-358	444	-32	11	-1820	107	0.63	0.73	49	36	1.56	0.89	2452	2532
2713	JEEP	GRAND CHEROKE	1998	609	948	-456	345	-8	43	-3394	643	0.81	0.99	56	36	2.99	0.97	6688	7183
2714	CHEVROLET	MALIBU	1998	465	691	-1013	334	-58	44	-849	1350	0.64	0.69	42	39	2.33	0.84	3392	3614
2725	BUICK	CENTURY	1998	683	887	-327	777	-18	18	-1191	2850	0.71	0.87	47	32	1.80	0.83	3400	2689
2726	TOYOTA	COROLLA	1998	508	722	-394	863	-35	88	-959	2350	0.78	0.83	45	37	1.67	0.85	5922	4133
2731	FORD	ESCORT	1998	518	681	-789	113	-31	39	-85	2238	0.62	0.75	55	38	1.73	0.97	2647	3983
2735	HONDA	CIVIC	1998	486	620	-335	354	-23	32	-1157	2141	0.52	0.62	50	40	1.90	0.94	4476	4406
2741	TOYOTA	AVALON	1998	331	513	-650	222	-12	27	-292	2035	0.54	0.63	50	21	0.84	0.77	2621	5658
2742	CHEVROLET	LUMINA	1998	514	679	-127	440	-26	14	-176	2362	0.73	0.87	48	26	1.07	0.78	4796	5978
2744	NISSAN	ALTIMA	1998	635	887	-378	633	-28	19	-2048	200	0.63	0.73	51	36	1.84	0.91	2920	1317
2746	TOYOTA	4RUNNER	1998	500	760	-751	158	-56	63	-3156	3750	1.06	1.23	57	52	2.21	1.13	7173	4428
2747	FORD	F150 PICKUP	1998	247	497	-345	438	-34	40	-1113	2771	0.64	0.80	42	42	1.81	0.88	5297	6648
2748	FORD	TAURUS	1998	411	577	-533	416	-28	31	-370	3148	0.79	0.94	49	36	1.88	0.89	4369	4351
2749	FORD	EXPLORER	1998	263	567	-924	76	-72	36	-488	3237	1.11	1.25	56	35	2.09	0.96	4793	6027
2750	CHEVROLET	VENTURE	1998	494	538	-913	353	-40	13	-601	2982	0.85	1.01	43	29	1.48	0.76	5825	4114
2751	CHEVROLET	S-10	1998	461	634	-721	775	-36	58	-714	2687	0.72	0.86	55	46	2.21	1.05	8312	4959
2756	CHEVROLET	BLAZER	1998	564	675	-811	283	-47	51	-236	2770	0.86	1.01	51	27	1.90	0.83	7873	6335
2763	ISUZU	RODEO	1998	364	676	-609	516	-32	53	-964	2536	0.59	0.72	60	36	2.61	1.02	5231	4559
2764	FORD	CROWN VICTORIA	1998	372	602	-397	330	-21	46	-599	3175	0.75	0.92	39	36	2.06	0.78	4432	3518
2765	SATURN	SL2	1998	277	435	-511	721	-20	87	-262	1662	0.64	0.67	40	41	1.42	0.84	NA	2047
2766	TOYOTA	SIENNA	1998	331	468	-537	568	-27	64	-222	1447	0.42	0.48	43	31	1.45	0.78	1184	1874
2767	TOYOTA	TACOMA	1998	494	731	-913	153	-46	31	-1269	3125	0.94	1.11	51	48	2.53	1.04	6259	3774
2770	CHEVROLET	SUBURBAN	1998	412	595	-347	221	-32	30	-500	2601	0.62	0.76	44	36	1.70	0.84	6867	7102
2771	NISSAN	SENTRA	1998	680	898	-651	306	-35	41	-345	2399	0.66	0.76	49	41	1.87	0.94	2310	2414
2772	DODGE	DURANGO	1998	462	997	-848	567	-80	14	-763	4448	1.36	1.59	62	49	2.94	1.17	6192	4138
2781	LEXUS	ES300	1998	292	512	-697	314	-9	46	-129	1435	0.39	0.45	50	24	1.22	0.79	4155	4612
2782	NISSAN	MAXIMA	1998	356	570	-249	339	-18	30	-157	1502	0.45	0.53	48	30	1.78	0.82	5142	4329
2783	CHEVROLET	CAMARO	1998	281	469	-132	759	-38	26	-347	2372	0.65	0.78	45	32	1.70	0.81	2796	2832
2784	DODGE	RAM1500	1998	499	691	-416	516	-35	3	-756	2528	0.62	0.73	47	28	2.05	0.79	3955	3315
2785	DODGE	DAKOTA	1998	319	550	-353	550	-59	37	-963	3040	0.84	1.00	51	30	1.73	0.85	3552	3542
2804	HONDA	CRV	1998	252	453	-184	680	-41	67	-376	2342	0.71	0.82	57	29	1.16	0.92	3408	3436
2805	TOYOTA	RAV4	1998	303	434	-518	486	-31	49	-271	1564	0.46	0.53	49	46	2.35	0.99	2655	3400
2806	FORD	MUSTANG	1998	245	435	-228	389	-15	38	-513	1729	0.43	0.51	41	29	1.24	0.74	3467	4004
2807	FORD	EXPEDITION	1998	334	544	-559	249	-24	51	-392	1843	0.47	0.56	45	34	1.86	0.82	5389	3734
2808	SUBARU	LEGACY	1998	303	525	-105	673	-22	43	-207	1761	0.47	0.56	51	35	2.12	0.91	2598	1912
2809	CHEVROLET	C-1500	1998	521	726	-219	359	-33	35	-279	2191	0.64	0.75	46	40	1.69	0.90	5627	5782
2814	NISSAN	FRONTIER	1998	716	1000	-559	350	-45	28	-692	3193	0.74	0.91	46	45	2.33	0.95	1813	4309
2815	HONDA	ACCORD	1998	308	454	-548	200	-13	49	-245	1193	0.42	0.45	51	37	1.49	0.93	806	2225
2820	VOLVO	S70	1998	128	259	-530	266	-11	27	-87	1679	0.43	0.51	46	39	2.22	0.89	2869	4952
2821	OLDSMOBILE	INTRIGUE	1998	354	589	-287	212	-8	38	-236	1588	0.46	0.52	47	33	1.68	0.84	4207	2727
2845	MERCEDES	OTHER	1998	346	510	-678	466	-35	43	-550	2343	0.56	0.68	50	37	1.67	0.91	4934	3675
	Average			*423*	*623*	*-472*	*459*	*-31*	*41*	*-724*	*2080*	*0.65*	*0.75*	*49*	*36*	*1.89*	*0.89*	*4415*	*4202*
	Pass			*49*	*50*			*48*	*52*	*52*	*50*	*49*	*45*	*50*	*52*		*44*	*51*	*52*
	Total Vehicles			*52*	*52*			*52*	*52*	*52*	*52*	*52*	*52*	*52*	*52*		*52*	*51*	*52*
	Pass Rate			*94%*	*96%*			*92%*	*100%*	*100%*	*96%*	*94%*	*87%*	*96%*	*100%*		*85%*	*100%*	*100%*

Table B.6

1998 NCAP Tests - Belted 50th Percentile Male ATD In Passenger Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	1000			-57	190	-4000	3300	1.00	1.00	60	63		1.00	10000	10000
2643	FORD	WINDSTAR	1998	184	294	-668	368	-45	21	-2177	49	0.51	0.62	38	16	0.09	0.58	1786	4304
2676	DODGE	STRATUS	1998	436	641	-571	287	-21	19	-1182	2401	0.57	0.71	54	35	1.71	0.93	4050	4197
2683	DODGE	CARAVAN	1998	530	788	-288	672	-18	66	-822	1585	0.39	0.47	53	40	1.52	0.98	5983	5975
2684	FORD	RANGER	1998	352	545	-611	617	-31	54	-779	1096	0.40	0.42	43	30	1.33	0.76	2966	1698
2688	CHEVROLET	CAVALIER	1998	395	620	-414	402	-28	27	-181	1137	0.32	0.38	47	33	1.35	0.83	3160	3301
2689	CHEVROLET	CAVALIER	1998	478	751	-439	693	-27	36	-443	1054	0.33	0.37	48	40	2.12	0.92	3440	3783
2691	FORD	WINDSTAR	1998	298	470	-451	27	-35	26	-82	1454	0.55	0.62	38	30	2.28	0.71	2074	3868
2708	FORD	CONTOUR	1998	410	617	-326	667	-11	85	-65	1368	0.42	0.47	49	30	2.00	0.84	5516	4441
2709	DODGE	NEON	1998	358	533	-535	306	-22	26	-140	2406	0.60	0.74	50	35	2.48	0.89	5566	3239
2710	TOYOTA	CAMRY	1998	284	488	-324	217	-29	16	-1182	256	0.32	0.38	38	31	1.10	0.71	3368	1107
2711	DODGE	GRAND CARAVAN	1998	627	994	-341	542	-36	18	-2210	537	0.74	0.86	60	37	1.82	1.03	7744	6544
2712	HONDA	ACCORD	1998	340	596	-554	82	-45	30	-1407	243	0.44	0.46	52	36	1.57	0.93	2644	1912
2713	JEEP	GRAND CHEROKE	1998	338	546	-188	775	-54	12	-1727	701	0.69	0.76	58	41	5.18	1.04	6657	6567
2714	CHEVROLET	MALIBU	1998	276	473	-549	448	-22	31	-214	1517	0.42	0.48	50	35	2.09	0.90	5633	2352
2725	BUICK	CENTURY	1998	918	1325	-447	1337	-25	83	-1270	1311	0.54	0.55	56	30	1.57	0.92	6321	4559
2726	TOYOTA	COROLLA	1998	336	566	-315	433	-27	40	-478	1168	0.31	0.35	47	32	1.40	0.83	4308	2059
2731	FORD	ESCORT	1998	421	532	-321	671	-10	17	-1331	3206	0.76	0.93	64	33	1.46	1.03	6093	10968
2735	HONDA	CIVIC	1998	373	531	-1138	172	-21	65	-524	902	0.32	0.33	55	28	1.35	0.88	3406	3929
2741	TOYOTA	AVALON	1998	388	577	-174	427	-15	26	-243	1133	0.29	0.35	37	28	1.04	0.68	1624	1237
2742	CHEVROLET	LUMINA	1998	288	495	-671	324	-10	38	-222	983	0.34	0.36	40	28	1.41	0.72	3743	2444
2744	NISSAN	ALTIMA	1998	713	1119	-647	207	-10	28	-2575	448	0.58	0.72	55	36	2.04	0.97	4245	2659
2746	TOYOTA	4RUNNER	1998	550	743	-544	324	-26	40	-408	2798	0.66	0.80	59	52	2.55	1.15	4477	5295
2747	FORD	F150 PICKUP	1998	363	615	-480	426	-27	27	-1048	2156	0.54	0.65	46	42	1.71	0.92	5191	4028
2748	FORD	TAURUS	1998	297	486	-873	466	-19	49	-1049	1308	0.42	0.46	51	28	1.54	0.84	4623	3809
2749	FORD	EXPLORER	1998	392	558	-661	645	-23	50	-820	2315	0.67	0.76	55	26	1.41	0.86	4189	3674
2750	CHEVROLET	VENTURE	1998	752	962	-1339	314	-92	2	-1212	2652	1.17	1.29	48	30	2.44	0.82	6614	3577
2751	CHEVROLET	S-10	1998	232	450	-999	414	-68	45	-501	2316	0.98	1.10	56	29	2.48	0.90	6726	4009
2756	CHEVROLET	BLAZER	1998	344	503	-787	479	-29	48	-443	2257	0.57	0.67	56	19	1.50	0.80	5762	5136
2763	ISUZU	RODEO	1998	422	631	-315	590	-61	50	-1425	1598	0.60	0.64	54	36	3.16	0.95	7004	3586
2764	FORD	CROWN VICTORIA	1998	168	335	-902	342	-33	41	-376	1909	0.61	0.71	40	29	2.16	0.73	2277	2570
2765	SATURN	SL2	1998	356	585	-860	260	-42	35	-397	2643	0.69	0.83	44	35	1.47	0.83	4906	4038
2766	TOYOTA	SIENNA	1998	237	395	-770	103	-61	36	-89	1266	0.68	0.73	42	34	1.62	0.80	1848	3768
2767	TOYOTA	TACOMA	1998	451	683	-447	309	-33	59	-775	2611	0.72	0.83	55	47	2.25	1.06	5050	3000
2770	CHEVROLET	SUBURBAN	1998	345	589	-984	34	-61	57	-389	2620	1.07	1.21	47	46	1.99	0.96	3405	2695
2771	NISSAN	SENTRA	1998	546	797	-817	338	-31	19	-316	2098	0.51	0.62	50	44	1.90	0.98	2690	2687
2772	DODGE	DURANGO	1998	340	627	-1002	233	-46	58	-632	2595	0.94	1.08	62	34	1.81	1.02	5288	4603
2781	LEXUS	ES300	1998	295	479	-529	121	-15	21	-420	1029	0.26	0.30	48	25	1.40	0.78	1202	1435
2782	NISSAN	MAXIMA	1998	409	647	-236	682	-25	13	-460	2460	0.68	0.80	54	30	1.76	0.89	4802	1900
2783	CHEVROLET	CAMARO	1998	169	328	-214	773	-27	65	-437	2000	0.47	0.58	38	23	1.13	0.65	2842	2602
2784	DODGE	RAM1500	1998	212	330	-188	1508	-72	44	-525	2608	1.03	1.17	49	27	1.57	0.81	4068	5259
2785	DODGE	DAKOTA	1998	338	563	-133	944	-35	60	-195	1814	0.52	0.62	50	38	2.73	0.92	5292	2002
2804	HONDA	CRV	1998	213	438	-209	839	-23	72	-611	1321	0.39	0.46	44	27	1.69	0.75	5215	2307
2805	TOYOTA	RAV4	1998	203	355	-214	704	-39	56	-362	1661	0.38	0.47	46	31	1.46	0.81	3292	3221
2806	FORD	MUSTANG	1998	206	364	-76	776	-43	40	-393	1855	0.65	0.72	47	38	2.33	0.89	4160	1567
2807	FORD	EXPEDITION	1998	331	569	-138	318	-33	30	-431	1570	0.40	0.47	42	38	1.92	0.84	2174	2355
2808	SUBARU	LEGACY	1998	371	623	-197	504	-42	31	-1333	1632	0.49	0.57	49	38	2.28	0.91	1836	4131
2809	CHEVROLET	C-1500	1998	398	693	-79	1172	-63	56	-457	2378	1.01	1.14	57	35	1.61	0.98	1778	2936
2814	NISSAN	FRONTIER	1998	310	521	-585	1457	-28	164	-724	1188	0.67	0.58	54	30	2.14	0.89	2134	4406
2815	HONDA	ACCORD	1998	389	642	-794	124	-55	38	-99	1455	0.65	0.71	48	35	1.45	0.88	1072	3494
2820	VOLVO	S70	1998	138	294	-395	392	-27	40	-305	1161	0.28	0.33	41	25	1.76	0.70	2658	3500
2821	OLDSMOBILE	INTRIGUE	1998	819	1139	-847	148	-19	70	-189	1153	0.30	0.35	49	35	1.28	0.88	3340	3210
2845	MERCEDES	OTHER	1998	134	227	-893	557	-14	71	-772	386	0.31	0.18	47	22	1.57	0.89	5282	4126
	Average			***374***	***590***	***-528***	***499***	***-34***	***43***	***-708***	***1611***	***0.56***	***0.64***	***49***	***33***	***1.83***	***0.87***	***4068***	***3578***
	Pass			***48***	***48***			***45***	***52***	***52***	***52***	***48***	***46***	***50***	***52***		***46***	***52***	***51***
	Total Vehicles			***52***	***52***			***52***	***52***	***52***	***52***	***52***	***52***	***52***	***52***		***52***	***52***	***52***
	Pass Rate			***92%***	***92%***			***87%***	***100%***	***100%***	***100%***	***92%***	***88%***	***96%***	***100%***		***88%***	***100%***	***98%***

Table B.7

1999 NCAP Tests - Belted 50th Percentile Male ATD In Driver Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	**1000**			**-57**	**190**	**-4000**	**3300**	**1.00**	**1.00**	**60**	**63**		**1.00**	**10000**	**10000**
2913	FORD	TAURUS	1999	310	467	-391	402	-24	41	-114	1668	0.43	0.51	44	NA	2.50	NA	2186	2508
2959	FORD	WINDSTAR	1999	178	319	-471	51	-14	29	-125	927	0.29	0.32	32	24	2.50	0.59	3763	2624
2967	PONTIAC	GRAND AM	1999	357	570	-221	664	-21	32	-135	1316	0.38	0.43	46	20	1.46	0.70	5009	4458
2968	SATURN	SL1	1999	250	420	-264	664	-21	62	-110	1709	0.57	0.61	42	35	1.71	0.80	1877	3178
2969	HONDA	CIVIC	1999	294	424	-497	145	-33	40	-1050	1620	0.46	0.55	50	34	1.49	0.88	4555	4480
2992	TOYOTA	TACOMA	1999	490	701	-506	372	-22	45	-528	2620	0.60	0.74	44	35	1.66	0.82	5102	3156
2993	HONDA	CIVIC	1999	282	428	-479	164	-19	47	-194	1628	0.38	0.47	47	34	1.78	0.86	4787	4092
2996	TOYOTA	4RUNNER	1999	395	693	-408	580	-21	31	-433	2174	0.51	0.62	45	37	1.94	0.85	3855	3829
2997	DODGE	GRAND CARAVAN	1999	593	801	-363	180	-26	51	-52	1858	0.52	0.61	47	46	2.40	0.96	6695	6098
3001	MAZDA	323-PROTEGE	1999	356	445	-518	156	-43	43	-308	3121	0.94	1.10	55	28	1.97	0.89	5225	6328
3002	CHEVROLET	TAHOE	1999	405	618	-404	518	-23	32	-407	2093	0.50	0.62	48	33	2.39	0.86	9550	7554
3003	NISSAN	ALTIMA	1999	668	908	-211	463	-12	30	-193	1899	0.52	0.60	51	33	1.57	0.89	1770	3328
3004	MITSUBISHI	GALANT	1999	351	439	-352	244	-24	31	-261	1892	0.52	0.62	50	31	2.12	0.85	3220	4478
3005	DODGE	INTREPID	1999	524	727	-281	466	-15	24	-175	2789	0.68	0.82	53	32	1.58	0.90	7497	6798
3006	FORD	EXPEDITION	1999	404	583	-248	506	-12	38	-727	2224	0.56	0.65	47	31	1.32	0.82	5005	4034
3007	OLDSMOBILE	INTRIGUE	1999	393	571	-289	796	-12	43	-252	1473	0.38	0.45	46	26	1.66	0.76	4509	4375
3009	MAZDA	626	1999	341	442	-351	589	-14	33	-155	1025	0.31	0.35	46	25	1.56	0.75	4209	2630
3013	DODGE	DURANGO	1999	510	1008	-1107	721	-79	19	-510	3432	1.07	1.18	61	41	2.31	1.07	7012	4294
3016	FORD	MUSTANG	1999	381	525	-632	122	-33	35	-814	3026	0.83	0.99	49	35	2.98	0.89	3912	6155
3021	FORD	E150 VAN	1999	276	538	-610	434	-25	56	-237	1524	0.49	0.53	56	39	1.53	1.00	4092	2909
3022	JEEP	CHEROKEE	1999	401	824	-913	91	-42	20	-417	3015	0.99	1.15	61	38	3.01	1.05	4955	9648
3023	DODGE	RAM	1999	452	775	-331	69	-35	21	-591	2645	0.75	0.87	53	44	2.28	1.02	4783	3661
3029	CHEVROLET	ASTRO	1999	315	528	-445	1584	-17	76	-928	1973	0.59	0.64	65	17	1.91	0.89	8803	4714
3031	SUBARU	FORESTER	1999	314	675	-286	256	-23	39	-302	2244	0.52	0.64	47	46	2.03	0.97	4848	5755
3032	CHEVROLET	BLAZER	1999	605	800	-276	1082	-26	56	-322	1946	0.58	0.65	65	39	2.82	1.10	7005	5880
3044	CHEVROLET	S-10	1999	713	901	-296	926	-35	38	-444	2629	0.69	0.81	71	51	3.18	1.28	7467	7982
3045	HONDA	ODYSSEY	1999	184	309	-393	414	-28	33	-123	1133	0.28	0.33	40	22	1.32	0.66	2692	2863
3046	FORD	F150 PICKUP	1999	277	517	-542	61	-53	63	-580	2305	0.57	0.70	46	45	2.49	0.94	6298	5533
3047	JEEP	WRANGLER	1999	282	589	-445	92	-27	41	-110	2749	0.63	0.78	55	62	3.92	1.21	5843	3944
3051	VOLKSWAGEN	BEETLE	1999	186	386	-382	589	-25	40	-306	2270	0.61	0.71	47	28	2.18	0.79	2166	2728
3052	CHEVROLET	C-1500	1999	730	966	-283	641	-30	53	-373	2223	0.53	0.64	62	37	1.66	1.05	5990	12545
3053	BUICK	CENTURY	1999	420	599	-162	664	-20	70	-209	1282	0.47	0.48	43	30	1.63	0.77	4610	2613
3057	JEEP	GRAND CHEROKE	1999	739	998	-587	217	-42	32	-972	3380	1.01	1.20	55	32	1.65	0.92	7393	7870
3058	FORD	EV RANGER	1999	210	372	-310	238	-17	15	-685	1958	0.52	0.62	37	28	1.29	0.69	4514	6302
3063	NISSAN	PATHFINDER	1999	682	835	-336	215	-35	35	-390	1920	0.50	0.60	44	39	1.33	0.86	1813	1538
3129	ACURA	3.5 RL	1999	433	576	-295	523	-30	36	-320	1521	0.35	0.43	56	34	1.25	0.95	942	1457
	Average			***408***	***619***	***-413***	***442***	***-27***	***40***	***-385***	***2089***	***0.57***	***0.67***	***50***	***34***	***2.01***	***0.89***	***4832***	***4787***
	Pass			***33***	***35***			***35***	***36***	***36***	***34***	***34***	***32***	***30***	***35***		***28***	***36***	***35***
	Total Vehicles			***36***	***36***			***36***	***36***	***36***	***36***	***36***	***36***	***36***	***35***		***35***	***36***	***36***
	Pass Rate			***92%***	***97%***			***97%***	***100%***	***100%***	***94%***	***94%***	***89%***	***83%***	***100%***		***80%***	***100%***	***97%***

Table B.8

1999 NCAP Tests - Belted 50th Percentile Male ATD In Passenger Postion

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Acc.	Chest Comp.	Vel.	CTI v2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test																		
				700	**1000**			**-57**	**190**	**-4000**	**3300**	**1.00**	**1.00**	**60**	**63**		**1.00**	**10000**	**10000**
2913	FORD	TAURUS	1999	340	480	-358	303	-39	38	-159	1932	0.45	0.55	41	NA	2.83	NA	4693	2843
2959	FORD	WINDSTAR	1999	312	548	-491	95	-18	17	-107	1540	0.36	0.44	36	26	2.12	0.65	2822	2341
2967	PONTIAC	GRAND AM	1999	352	545	-361	444	-13	38	-394	1424	0.43	0.49	43	29	1.48	0.76	5436	3829
2968	SATURN	SL1	1999	311	479	-402	814	-12	47	-346	1077	0.37	0.39	41	20	1.29	0.65	5209	3176
2969	HONDA	CIVIC	1999	346	544	-510	304	-18	33	-713	1882	0.46	0.55	48	34	1.77	0.86	4654	3991
2992	TOYOTA	TACOMA	1999	356	479	-733	774	-30	55	-742	857	0.33	0.33	47	20	1.84	0.72	4595	3455
2993	HONDA	CIVIC	1999	470	696	-1042	217	-24	58	-360	2218	0.54	0.65	47	37	1.26	0.88	3484	4125
2996	TOYOTA	4RUNNER	1999	266	438	-549	578	-26	53	-489	1323	0.38	0.43	43	40	2.43	0.87	4674	2740
2997	DODGE	GRAND CARAVAN	1999	608	814	-695	140	-15	42	-21	1511	0.39	0.46	45	29	1.84	0.78	5744	6149
3001	MAZDA	323-PROTEGE	1999	355	534	-392	494	-19	33	-251	1578	0.47	0.56	50	23	1.58	0.79	5411	3048
3002	CHEVROLET	TAHOE	1999	400	620	-1016	155	-24	56	-826	2782	0.76	0.92	51	38	2.13	0.94	1424	4404
3003	NISSAN	ALTIMA	1999	481	834	-621	77	-26	24	-169	2117	0.61	0.73	50	35	1.71	0.89	3639	2588
3004	MITSUBISHI	GALANT	1999	284	550	-730	136	-43	32	-153	2034	0.73	0.83	47	28	1.96	0.79	3001	3737
3005	DODGE	INTREPID	1999	373	542	-448	521	-25	41	-183	1165	0.34	0.39	51	24	1.24	0.80	5621	5631
3006	FORD	EXPEDITION	1999	414	680	-613	139	-23	37	-424	1906	0.58	0.68	44	33	1.68	0.80	3065	2853
3007	OLDSMOBILE	INTRIGUE	1999	902	1163	-320	1114	-24	53	-519	1291	0.44	0.47	52	18	0.96	0.75	5030	4780
3009	MAZDA	626	1999	116	248	-916	156	-50	78	-131	1970	0.81	0.91	47	21	1.98	0.73	5314	5208
3013	DODGE	DURANGO	1999	267	592	-765	514	-36	77	-1045	1870	0.57	0.67	54	36	1.81	0.95	5041	5214
3016	FORD	MUSTANG	1999	610	871	-1243	106	-42	5	-82	3510	1.08	1.27	40	39	2.32	0.82	5769	1815
3021	FORD	E150 VAN	1999	423	634	-424	785	-18	40	-207	1716	0.51	0.57	54	28	3.14	0.88	4169	7738
3022	JEEP	CHEROKEE	1999	280	475	-458	301	-31	41	-488	2301	0.63	0.72	65	15	0.80	0.87	8161	5544
3023	DODGE	RAM	1999	376	586	-925	77	-59	48	-552	2480	0.91	1.04	47	14	0.62	0.66	3635	4480
3029	CHEVROLET	ASTRO	1999	183	301	-590	1153	-28	61	-520	982	0.38	0.39	51	25	2.85	0.81	7122	6196
3031	SUBARU	FORESTER	1999	295	496	-746	170	-21	59	-19	1734	0.39	0.48	48	36	1.84	0.88	5374	5270
3032	CHEVROLET	BLAZER	1999	282	406	-650	522	-39	68	-1565	1963	0.54	0.59	57	26	1.81	0.89	5404	4875
3044	CHEVROLET	S-10	1999	336	588	-1007	124	-65	57	-335	2594	0.96	0.25	59	38	2.42	1.02	7155	2677
3045	HONDA	ODYSSEY	1999	267	379	-640	144	-14	40	-131	1366	0.41	1.08	38	22	1.19	0.63	2695	3042
3046	FORD	F150 PICKUP	1999	352	634	-622	124	-26	31	-437	2034	0.53	0.48	45	42	2.49	0.91	5074	4232
3047	JEEP	WRANGLER	1999	511	748	-313	207	-20	13	-246	1715	0.50	0.59	45	39	1.96	0.88	4967	4130
3051	VOLKSWAGEN	BEETLE	1999	295	443	-485	783	-34	40	-231	1211	0.36	0.40	48	29	2.17	0.82	5761	5174
3052	CHEVROLET	C-1500	1999	1036	1191	-418	495	-32	38	-260	2232	0.59	0.69	53	34	1.61	0.92	5850	5652
3053	BUICK	CENTURY	1999	801	1062	-124	928	-28	55	-382	803	0.24	0.27	50	24	1.21	0.78	4938	3217
3057	JEEP	GRAND CHEROKEE	1999	405	773	-414	541	-18	47	-651	1930	0.47	0.56	54	24	1.47	0.83	9276	7062
3058	FORD	EV RANGER	1999	272	410	-49	52	-28	36	-170	1382	0.51	0.58	39	28	1.28	0.70	3748	3422
3063	NISSAN	PATHFINDER	1999	202	364	-574	360	-24	55	-242	1259	0.43	0.46	43	39	1.53	0.85	2173	2879
3129	ACURA	3.5 RL	1999	407	559	-506	433	-16	51	-474	1339	0.46	0.49	53	31	1.74	0.89	1263	1142
	Average			***397***	***603***	***-587***	***397***	***-28***	***44***	***-390***	***1751***	***0.52***	***0.59***	***48***	***29***	***1.79***	***0.82***	***4761***	***4129***
	Pass			***33***	***33***			***34***	***36***	***36***	***35***	***35***	***33***	***35***	***35***		***34***	***36***	***36***
	Total Vehicles			***36***	***36***			***36***	***36***	***36***	***36***	***36***	***36***	***36***	***35***		***35***	***36***	***36***
	Pass Rate			***92%***	***92%***			***94%***	***100%***	***100%***	***97%***	***97%***	***92%***	***97%***	***100%***		***97%***	***100%***	***100%***

Table B.9 1996-1997 FMVSS Unbelted 208 Tests - 50th Percentile Male ATD In Driver Position

Neck Loads not measured

TSTNO	MAKE	MODEL	YEAR	HIC15	HIC_36	ACCEL.	CHEST DEFL.	VEL.	CTI_2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test										
				700	**1000**	**60**	**63**		**1.00**		
2279	DODGE	CARAVAN	1996	294	447	48	45	3.40	0.96	6802	6238
2314	MITSUBISHI	MIRAGE	1996	110	215	55	56	6.50	1.15	4999	5399
2317	PONTIAC	BONNEVILLE	1996	138	209	42	33	1.80	0.78	5408	6462
2334	LINCOLN	TOWN CAR	1996	74	153	41	33	1.90	0.78	6075	3715
2362	HONDA	CIVIC	1996	88	149	51	48	2.80	1.03	4237	5975
2369	HYUNDAI	ACCENT	1996	209	346	51	40	3.00	0.95	5585	7840
2377	HYUNDAI	SONATA	1996	224	292	62	58	3.10	1.26	7055	5447
2378	TOYOTA	4RUNNER	1996	644	806	58	26	1.00	0.90	5627	6924
2390	TOYOTA	CELICA	1996	378	502	46	31	1.20	0.80	4589	6834
2406	ISUZU	RODEO	1996	96	122	36	51	2.80	0.89	9060	5360
2412	NISSAN	PICKUP	1996	380	469	53	46	3.90	1.03	6725	7018
2434	DODGE	NEON	1996	170	238	47	30	3.70	0.82	6736	7094
2441	JEEP	CHEROKEE	1996	282	385	47	39	2.30	0.90	2909	3591
2449	DODGE	INTREPID	1996	239	382	41	34	3.30	0.78	6535	7064
2442	TOYOTA	TACOMA	1996	321	438	46	47	4.50	0.97	7207	5077
2443	NISSAN	PATHFINDER	1996	318	423	51	46	4.00	1.01	5911	4598
2444	ISUZU	TROOPER II	1996	86	149	45	59	3.50	1.08	8768	7138
2450	FORD	TAURUS	1996	337	491	50	33	2.90	0.88	4844	4834
2437	FORD	F150 PICKUP	1997	278	340	49	31	2.60	0.85	6887	8112
2463	CHRYSLER	SEBRING CONVERTI	1997	401	445	52	25	1.40	0.83	8205	7411
2462	LINCOLN	MARK	1997	46	75	25	29	2.40	0.55	7374	5385
2468	SATURN	SL1	1997	260	260	33	41	1.97	0.77	4531	4517
2469	MITSUBISHI	GALANT	1997	74	135	52	57	4.30	1.13	6107	6323
2489	PONTIAC	GRAND AM	1997	257	340	54	39	1.80	0.98	5177	4700
2497	CADILLAC	ELDORADO	1997	116	188	46	28	0.80	0.78	4534	5730
2498	FORD	E150 VAN	1997	162	263	47	31	1.70	0.83	6195	6229
2467	FORD	EXPEDITION	1997	201	330	42	28	1.30	0.74	6711	8704
2558	CHEVROLET	S-10	1997	319	486	38	40	1.80	0.81	4619	3236
	Average			***232***	***324***	***47***	***39***	***2.70***	***0.90***	***6050***	***5963***
	Pass			***28***	***28***	***27***	***28***		***21***	***28***	***28***
	Total Vehicles			***28***	***28***	***28***	***28***		***28***	***28***	***28***
	Pass Rate			***100%***	***100%***	***96%***	***100%***		***75%***	***100%***	***100%***

Table B.10 1996-1997 FMVSS Unbelted 208 Tests - 50th Percentile Male ATD In Passenger Position

Neck Loads not measured

TSTNO	MAKE	MODEL	YEAR	HIC15	HIC_36	ACCEL.	CHEST DEFL.	VEL.	CTI_2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test										
				700	**1000**	**60**	**63**		**1.00**	10000	10000
2279	DODGE	CARAVAN	1996	70	130	39	25	2.80	0.67	8156	7798
2314	MITSUBISHI	MIRAGE	1996	456	567	62	19	2.30	0.87	6758	6858
2317	PONTIAC	BONNEVILLE	1996	309	453	50	12	2.50	0.67	5649	4888
2334	LINCOLN	TOWN CAR	1996	106	133	37	13	0.99	0.54	4248	5164
2362	HONDA	CIVIC	1996	305	305	43	16	0.89	0.63	5829	6225
2369	HYUNDAI	ACCENT	1996	152	182	41	17	2.00	0.62	5111	6926
2377	HYUNDAI	SONATA	1996	136	249	39	21	2.30	0.64	7186	7530
2378	TOYOTA	4RUNNER	1996	236	286	46	19	2.20	0.70	4782	7530
2390	TOYOTA	CELICA	1996	148	265	44	25	2.40	0.73	6572	5912
2406	ISUZU	RODEO	1996	207	334	51	36	3.20	0.92	8176	6129
2412	NISSAN	PICKUP	1996	315	443	62	N/A	N/A	N/A	946	1409
2434	DODGE	NEON	1996	125	171	46	24	2.63	0.74	5714	7826
2441	JEEP	CHEROKEE	1996	176	299	48	25	1.92	0.78	4874	2909
2449	DODGE	INTREPID	1996	212	344	52	20	1.22	0.77	7982	7376
2442	TOYOTA	TACOMA	1996	215	397	46	36	2.10	0.86	2339	1896
2443	NISSAN	PATHFINDER	1996	809	809	53	27	3.26	0.85	6560	6659
2444	ISUZU	TROOPER II	1996	82	116	48	24	4.19	0.77	7313	8987
2450	FORD	TAURUS	1996	167	167	46	N/A	N/A	N/A	7428	7197
2437	FORD	F150 PICKUP	1997	149	231	45	14	0.96	0.63	7559	6495
2463	CHRYSLER	SEBRING CONVERTI	1997	449	483	52	24	2.07	0.81	6368	7058
2462	LINCOLN	MARK	1997	59	78	29	19	1.84	0.50	5216	4365
2468	SATURN	SL1	1997	139	236	42	13	1.30	0.59	6366	4914
2469	MITSUBISHI	GALANT	1997	154	234	38	26	2.04	0.67	5837	5162
2489	PONTIAC	GRAND AM	1997	222	147	52	13	1.79	0.70	7320	6172
2497	CADILLAC	ELDORADO	1997	263	350	48	18	2.05	0.71	5178	4427
2498	FORD	E150 VAN	1997	120	147	45	14	3.76	0.63	5454	7084
2467	FORD	EXPEDITION	1997	516	516	44	12	0.95	0.61	6415	7144
2558	CHEVROLET	S-10	1997	759	769	38	31	2.50	0.72	3264	4698
	Average			***252***	***316***	***46***	***21***	***2.16***	***0.70***	***5879***	***5955***
	Pass			***26***	***28***	***26***	***26***		***26***	***28***	***28***
	Total Vehicles			***28***	***28***	***28***	***26***		***26***	***28***	***28***
	Pass Rate			***93%***	***100%***	***93%***	***100%***		***100%***	***100%***	***100%***

Table B.11 1998 - 1999 FMVSS Unbelted 208 Tests - 50th Percentile Male ATD In Driver Position

Tstno	MAKE	MODEL	YEAR	HIC15	HIC_36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest ACCEL.	CHEST DEFL.	CTI_2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test													(g's)	(mm)			
				700	**1000**			**-57**	**190**	**-4000**	**3300**	**1.00**	**1.00**	**60**	**63**	**1.00**	**10000**	**10000**
2832	FORD	TAURUS	1998	181	290	-995	322	-14	37	-125	1577	0.38	0.46	47	32	0.83	5556	4881
2830	JEEP	G. CHEROKE	1998	189	278	-582	353	-17	35	-178	2071	0.53	0.63	46	42	0.92	7366	6710
2839	FORD	EXPLORER	1998	272	306	-1149	424	-14	43	-768	1071	0.30	0.36	44	22	0.70	5687	6033
2838	DODGE	NEON	1998	166	339	-951	44	-8	64	-293	1265	0.47	0.49	44	25	0.73	6447	7336
2837	TOYOTA	CAMRY	1998	231	263	-1223	167	-8	75	-304	1053	0.45	0.45	52	38	0.95	6115	5810
2773	DODGE	CARAVAN	1998	350	507	-180	602	-16	14	-206	2096	0.47	0.59	48	55	1.07	7309	6434
2836	HONDA	ACCORD	1998	51	110	-560	261	-6	36	-259	824	0.27	0.29	38	46	0.87	3870	7622
3123	FORD	E150 VAN	1999	87	188	-243	499	-13	23	-544	1358	0.32	0.39	52	37	0.94	6198	5775
3124	FORD	EXPEDITION	1999	178	377	-171	758	-12	40	-183	1361	0.41	0.46	47	28	0.79	5952	6612
3125	ACURA	3.5 RL	1999	154	235	-454	800	-24	45	-104	756	0.29	0.30	57	32	0.94	13349	5338
3126	DODGE	INTREPID	1999	403	559	-170	651	-11	32	-208	2039	0.52	0.63	54	45	1.04	5282	7785
3127	SATURN	OTHER	1999	128	225	-155	762	-9	57	-207	1123	0.41	0.43	37	47	0.86	4933	5288
3128	TOYOTA	TACOMA	1999	176	301	-410	541	-19	42	-981	1203	0.33	0.38	44	48	0.96	8839	5346
	Average			***197***	***306***	***-557***	***476***	***-13***	***42***	***-335***	***1369***	***0.40***	***0.45***	***47***	***38***	***0.89***	***6685***	***6229***
	Pass			***13***	***13***			***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***11***	***12***	***13***
	Total Vehicles			***13***	***13***			***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***
	Pass Rate			***100%***	***100%***			***100%***	***100%***	***100%***	***100%***	***100%***	***100%***	***100%***	***100%***	***85%***	***92%***	***100%***

Table B.12 1998 - 1999 FMVSS Unbelted 208 Tests - 50th Percentile Male ATD In Passenger Position

Tstno	MAKE	MODEL	YEAR	HIC15	HIC_36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest ACCEL.	CHEST DEFL.	CTI_2	Femur Left	Femur Right
	Independent Neck Criteria based on 208 Sled Test													(g's)	(mm)			
				700	**1000**			**-57**	**190**	**-4000**	**3300**	**1.00**	**1.00**	**60**	**63**	**1.00**	**10000**	**10000**
2832	FORD	TAURUS	1998	191	299	-1419	351	-21	63	-990	1305	0.43	0.47	49	10	0.64	5697	5312
2830	JEEP	G. CHEROKE	1998	84	140	-1040	253	-27	100	-553	1003	0.49	0.48	49	12	0.66	7530	7921
2839	FORD	EXPLORER	1998	186	312	-1581	326	-19	50	-1009	594	0.31	0.35	48	9	0.62	5792	6339
2838	DODGE	NEON	1998	297	419	-1184	220	-23	40	-874	2211	0.59	0.69	61	16	0.83	6606	6289
2837	TOYOTA	CAMRY	1998	236	432	-1187	199	-24	48	-771	742	0.26	0.31	35	17	0.55	4119	5273
2773	DODGE	CARAVAN	1998	249	379	-356	1222	-14	70	-674	1354	0.48	0.51	53	20	0.78	6807	5556
2836	HONDA	ACCORD	1998	160	237	-2004	216	-21	84	-976	413	0.39	0.40	45	13	0.63	4677	4497
3123	FORD	E150 VAN	1999	87	188	-206	1478	-20	85	-634	630	0.35	0.31	46	7	0.58	6208	8038
3124	FORD	EXPEDITION	1999	132	148	-443	1637	-9	90	-1375	926	0.34	0.41	51	20	0.76	6730	6975
3125	ACURA	3.5 RL	1999	367	585	-92	1393	-20	107	-952	481	0.44	0.38	50	12	0.67	6854	7676
3126	DODGE	INTREPID	1999	223	401	-501	1205	-41	66	-1285	957	0.40	0.42	54	26	0.85	7486	7890
3127	SATURN	OTHER	1999	200	331	-160	613	-15	20	-615	2023	0.50	0.61	40	9	0.54	6374	5155
3128	TOYOTA	TACOMA	1999	173	220	-307	1761	-15	34	-766	3038	0.69	0.86	36	24	0.62	4959	6372
	Average			***199***	***315***	***-806***	***836***	***-21***	***66***	***-883***	***1206***	***0.44***	***0.48***	***47***	***15***	***0.67***	***6141***	***6407***
	Pass			***13***	***13***			***13***	***13***	***13***	***13***	***13***	***13***	***12***	***13***	***13***	***13***	***13***
	Total Vehicles			***13***	***13***			***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***	***13***
	Pass Rate			***100%***	***100%***			***100%***	***100%***	***100%***	***100%***	***100%***	***100%***	***92%***	***100%***	***100%***	***100%***	***100%***

Table B.13

1998-1999 TRANSPORT CANADA, 48 KMPH Belted 5th Percentile Female ATD in Driver Position

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Comp.	CTI v2	Femur Left	Femur Right
								AAMA	***AAMA***	***AAMA***	***AAMA***							
				700	**1000**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**	**6800**	**6800**
3072	GEO	METRO	1999	92	179	-1500	76	-86	9	-730	1874	1.70	1.76	48	30	0.90	2141	2033
3065	HONDA	CIVIC	1998	108	172	NA	83	-31	21	-205	1578	0.89	0.92	39	24	0.71	1268	1722
3066	CHEVROLET	MALIBU	1998	185	367	-234	214	-33	9	-586	1547	0.68	0.70	40	28	0.77	2614	912
3067	NISSAN	MAXIMA	1998	129	142	-1668	64	-81	26	-106	2540	1.99	3.05	43	25	0.77	566	851
3074	TOYOTA	CAMRY	1999	206	319	-143	129	-9	11	-39	1312	0.45	0.47	39	25	0.73	853	357
3094	HYUNDAI	ACCENT	1999	285	309	-1941	66	-87	17	-275	2564	2.17	2.25	56	28	0.96	NA	1824
3068	SUBARU	FORESTER	1998	157	198	-347	256	-36	25	-197	2088	0.96	1.01	49	32	0.93	2595	2071
3093	FORD	TAURUS	1999	93	151	-470	97	-32	41	-161	1598	0.93	0.97	38	27	0.75	784	1414
3069	FORD	WINDSTAR	1998	106	200	-148	100	-14	9	-286	832	0.45	0.47	37	25	0.71	2327	817
3070	CHEVROLET	VENTURE	1998	402	419	-222	181	-32	6	-268	1878	0.59	0.62	35	27	0.71	1313	1828
3071	FORD	RANGER	1999	190	205	-1269	126	-64	22	-405	2295	1.68	1.75	52	34	0.98	3743	3542
3179	CHEVROLET	CAVALIER	1999	200	294	-497	123	-36	18	-346	1786	1.08	1.13	46	26	0.82	3035	1176
3096	CHEVROLET	CAVALIER	1999	291	377	-135	174	-21	8	-373	1690	0.75	0.78	52	26	0.88	2781	1867
3098	CHRYSLER	INTREPID	1999	214	397	-166	170	-27	10	-298	1591	0.79	0.83	49	32	0.92	854	3775
3180	CHEVROLET	CAVALIER	1999	247	374	-283	87	-25	10	-282	1688	0.87	0.90	52	28	0.90	3121	3452
3073	PLYMOUTH	OTHER	1999	357	527	-139	122	-20	18	-241	1823	0.74	0.78	55	38	1.06	5487	1834
3095	ACURA	OTHER	1999	218	359	-1284	335	-60	10	-724	2229	1.63	1.70	43	36	0.91	225	170
2858	NISSAN	ALTIMA	1998	141	282	-296	207	-16	13	-169	1478	0.55	0.57	42	22	0.72	2036	3406
2859	TOYOTA	COROLLA	1998	324	415	-368	115	-28	5	-355	1955	0.70	0.73	37	18	0.62	2201	2095
2860	TOYOTA	TACOMA	1998	545	688	-497	53	-20	10	-435	2726	0.93	0.98	58	43	1.15	1815	310
2861	DODGE	NEON	1998	354	437	-150	248	-14	8	-338	1994	0.62	0.64	49	29	0.89	3435	3426
2862	HONDA	ACCORD	1998	225	321	-1050	112	-49	3	-328	1647	1.23	1.28	47	32	0.90	1613	779
2863	NISSAN	SENTRA	1998	199	342	-205	57	-15	4	-7	1363	0.61	0.64	37	20	0.66	3256	1477
2864	FORD	EXPLORER	1998	154	229	-1670	49	-65	13	-274	2180	1.69	1.76	58	40	1.12	3679	2828
2865	PLYMOUTH	VOYAGER VAN	1998	255	399	-231	156	-10	13	-368	1564	0.53	0.54	45	43	1.01	2530	3401
2866	MAZDA	626	1998	220	259	-1864	186	-84	12	-663	2149	1.91	1.99	47	24	0.81	237	2435
	Average			***227***	***321***	***-671***	***138***	***-38***	***13***	***-325***	***1845***	***1.04***	***1.12***	***46***	***29***	***0.86***	***2180***	***1915***
	Pass			***26***	***26***			***18***	***26***	***26***	***18***	***17***	***16***	***26***	***26***	***22***	***25***	***26***
	Total Vehicles			***26***	***26***			***26***	***26***	***26***	***26***	***26***	***26***	***26***	***26***	***26***	***25***	***26***
	Pass Rate			***100%***	***100%***			***69%***	***100%***	***100%***	***69%***	***65%***	***62%***	***100%***	***100%***	***85%***	***100%***	***100%***

Table B.14

1998-1999 TRANSPORT CANADA, 48 KMPH Belted 5th Percentile Female ATD in Passenger Position

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Comp.	CTI v2	Femur Left	Femur Right
								AAMA	*AAMA*	*AAMA*	*AAMA*							
				700	1000			-39	95	-2520	2070	1.00	1.00	60	52	1.00	6800	6800
3072	GEO	METRO	1999	52	69	-166	716	-12	56	-1100	649	0.51	0.47	42	16	0.66	2816	2902
3065	HONDA	CIVIC	1998	144	247	-811	80	-20	42	-268	1415	0.55	0.51	41	26	0.76	2635	3532
3066	CHEVROLET	MALIBU	1998	224	308	-261	442	-16	39	-469	563	0.38	0.33	38	26	0.73	2805	1629
3067	NISSAN	MAXIMA	1998	192	326	-172	662	-14	50	-1112	549	0.36	0.39	45	19	0.72	3493	1931
3074	TOYOTA	CAMRY	1999	276	390	-102	343	-7	37	-1721	210	0.59	0.60	37	22	0.68	1341	1266
3094	HYUNDAI	ACCENT	1999	301	612	-1316	63	-27	47	-1	1879	0.81	0.85	44	26	0.80	1298	754
3068	SUBARU	FORESTER	1998	65	142	-548	153	-25	28	-270	1060	0.70	0.73	42	24	0.74	2638	4196
3093	FORD	TAURUS	1999	148	218	-305	321	-19	28	-287	1081	0.51	0.54	37	18	0.62	2668	2692
3069	FORD	WINDSTAR	1998	67	122	-291	378	-17	15	-66	861	0.52	0.54	33	21	0.62	2334	1895
3070	CHEVROLET	VENTURE	1998	121	204	-467	499	-21	30	-492	1199	0.67	0.70	32	24	0.64	2020	1844
3071	FORD	RANGER	1999	295	378	-392	163	-29	28	-250	1402	0.86	0.90	39	21	0.68	4408	3639
3179	CHEVROLET	CAVALIER	1999	210	344	-263	367	-11	25	-255	1111	0.46	0.49	43	29	0.82	803	1446
3096	CHEVROLET	CAVALIER	1999	195	308	-315	158	-13	31	-149	948	0.41	0.43	37	26	0.72	NA	1476
3098	CHRYSLER	INTREPID	1999	199	291	-364	229	-23	24	-362	1070	0.53	0.55	38	25	0.73	3334	1399
3180	CHEVROLET	CAVALIER	1999	196	307	-431	341	-16	39	-110	1019	0.50	0.53	38	25	0.72	876	1755
3073	PLYMOUTH	OTHER	1999	456	642	-126	274	-10	13	-291	1924	0.68	0.72	51	30	0.92	3938	3459
3095	ACURA	OTHER	1999	357	522	-270	400	-14	26	-514	1030	0.43	0.45	51	34	0.98	2731	277
2858	NISSAN	ALTIMA	1998	296	476	-196	628	-11	74	-1342	188	0.87	0.77	40	12	0.58	2656	1480
2859	TOYOTA	COROLLA	1998	559	973	-1985	163	-5	29	-1901	577	0.64	0.65	43	19	0.70	2112	1427
2860	TOYOTA	TACOMA	1998	300	464	-628	500	-40	37	-372	1445	1.06	1.11	62	36	1.11	1883	2794
2861	DODGE	NEON	1998	303	415	-121	717	-7	47	-729	519	0.35	0.30	47	20	0.76	2503	4119
2862	HONDA	ACCORD	1998	269	351	-94	397	-22	15	-241	1057	0.50	0.53	44	23	0.76	3728	2254
2863	NISSAN	SENTRA	1998	244	372	-250	375	-20	29	-228	1064	0.48	0.50	45	27	0.82	1770	1656
2864	FORD	EXPLORER	1998	155	283	-213	379	-14	22	-585	1248	0.51	0.53	45	21	0.76	3925	3373
2865	PLYMOUTH	VOYAGER VAN	1998	318	403	-304	585	-20	37	-459	1476	0.75	0.79	48	31	0.90	4050	3435
2866	MAZDA	626	1998	262	297	-2302	111	-97	18	-219	2780	2.26	2.35	47	28	0.86	3287	2143
	Average			*239*	*364*	*-488*	*363*	*-20*	*33*	*-530*	*1089*	*0.65*	*0.66*	*43*	*24*	*0.76*	*2642*	*2260*
	Pass			*26*	*26*			*24*	*26*	*26*	*25*	*24*	*24*	*25*	*26*	*25*	*25*	*26*
	Total Vehicles			*26*	*26*			*26*	*26*	*26*	*26*	*26*	*26*	*26*	*26*	*26*	*25*	*26*
	Pass Rate			*100%*	*100%*			*92%*	*100%*	*100%*	*96%*	*92%*	*92%*	*96%*	*100%*	*96%*	*100%*	*100%*

Table B.15 TRANSPORT CANADA, 40% OFFSET, Belted 5th Percentile Female ATD in Driver Position

Tstno	Year	Closing Speed	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Comp.	CTI v2	Femur Left	Femur Right
		KMPH					*AAMA*	*AAMA*	*AAMA*	*AAMA*							
			700	**1000**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**	**6800**	**6800**
2879	1998	40	96	117	-1207	113	-57	16	-62	1498	1.29	1.34	16	19	0.40	83	683
2880	1998	40	27	45	-215	106	-9	16	-62	644	0.30	0.31	19	17	0.42	730	1172
2881	1998	40	311	356	-366	117	-21	15	-411	1534	0.61	0.63	27	20	0.54	1155	163
2882	1998	40	145	183	-391	188	-24	21	-68	1370	0.61	0.64	24	14	0.42	994	760
2883	1998	41	87	88	-1130	66	-56	35	-64	1463	1.26	1.31	17	14	0.36	2264	199
2884	1998	40	486	612	-3495	103	-127	6	-118	2828	2.68	2.79	35	26	0.70	1591	202
2885	1998	40	183	223	-1195	47	-30	12	-86	2573	0.98	1.03	25	24	0.56	1393	423
2886	1998	40	402	647	-2314	179	-77	6	-661	3494	2.02	2.10	23	28	0.59	1129	359
2887	1998	40	325	380	-858	482	-46	39	-582	2247	1.20	1.25	22	18	0.45	707	367
2888	1998	40	131	194	-413	113	-12	22	-22	2088	0.70	0.71	30	27	0.66	504	310
2889	1998	40	66	94	-1592	26	-69	2	-38	1184	1.42	1.47	23	22	0.52	606	313
3112	1998	40	58	82	-131	157	-8	13	-43	651	0.25	0.24	20	14	0.39	1798	288
3086	1999	38	22	30	-150	112	-16	11	-20	728	0.45	0.47	19	9	0.31	1590	294
3177	1998	40	111	148	-457	96	-35	17	-205	1484	0.93	0.97	20	14	0.38	835	21
3077	1999	40	25	30	-1282	54	-55	13	-9	1386	1.29	1.34	14	16	0.34	777	445
3178	1998	40	148	194	-257	115	-28	17	-216	1483	0.80	0.83	21	16	0.42	1198	106
3081	1999	36	95	124	-152	178	-21	19	-94	1109	0.60	0.62	20	13	0.37	713	605
3078	1999	33	265	283	-857	263	-54	8	-216	2315	1.42	1.48	21	15	0.42	428	594
3082	1999	36	177	225	-129	278	-15	25	-82	1141	0.49	0.47	21	18	0.45	72	63
3080	1999	38	276	296	-1326	57	-32	5	-36	2520	1.24	1.30	32	21	0.60	653	178
3079	1999	40	131	159	-150	119	-17	15	-147	1292	0.64	0.66	21	13	0.38	1603	985
3085	1999	40	376	558	-409	674	-41	65	-235	1942	0.99	1.03	24	20	0.51	235	450
3185	1999	34	165	199	-305	87	-10	23	-91	1523	0.60	0.58	17	16	0.38	158	637
3182	1999	41	343	383	-600	1146	-17	97	-183	2123	1.23	1.11	33	26	0.68	264	411
3083	1999	32	187	187	-583	63	-8	36	-28	712	0.34	0.30	21	16	0.43	1105	414
3076	1999	34	81	95	-342	70	-7	26	-79	500	0.19	0.17	17	13	0.35	913	216
3075	1999	36	33	51	-467	87	-11	26	-143	444	0.26	0.23	17	14	0.36	202	244
3184	1999	36	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	19	20	0.44	896	78
3084	1999	40	289	410	-370	164	-16	21	-32	1328	0.48	0.49	26	19	0.52	1916	1465
3181	1999	40	246	273	-530	57	-10	37	-225	835	0.37	0.39	26	21	0.54	787	122
Average			*182*	*230*	*-747*	*183*	*-32*	*23*	*-147*	*1532*	*0.88*	*0.88*	*22*	*18*	*0.46*	*910*	*419*
Pass			*29*	*29*			*20*	*28*	*29*	*21*	*19*	*17*	*30*	*30*	*30*	*30*	*30*
Total Vehicles			*29*	*29*			*29*	*29*	*29*	*29*	*29*	*30*	*30*	*30*	*30*	*30*	*30*
Pass Rate			*100%*	*100%*			*69%*	*97%*	*100%*	*72%*	*66%*	*57%*	*100%*	*100%*	*100%*	*100%*	*100%*

Table B.16 TRANSPORT CANADA, 40% OFFSET, Belted 5th Percentile Female ATD in Passenger Position

Tstno	Year	Closing Speed	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Comp.	CTI v2	Femur Left	Femur Right
		KMPH					*AAMA*	*AAMA*	*AAMA*	*AAMA*							
			700	**1000**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**	**6800**	**6800**
2879	1998	40	124	194	-276	515	-4	91	-1947	45	1.16	1.03	24	6	0.33	1414	72
2880	1998	40	19	37	-161	270	-5	13	-81	632	0.22	0.22	23	17	0.46	534	866
2881	1998	40	101	188	-615	80	-25	6	-103	1650	0.75	0.78	34	23	0.66	1663	542
2882	1998	40	373	629	-1705	135	-9	66	-1869	1900	0.84	0.79	31	18	0.56	877	501
2883	1998	41	12	25	-284	541	-6	41	-565	276	0.43	0.37	15	12	0.32	472	724
2884	1998	40	200	322	-106	717	-11	30	-83	1142	0.45	0.47	34	15	0.56	935	255
2885	1998	40	83	171	-135	862	-12	67	-1300	1022	0.80	0.71	27	10	0.42	843	655
2886	1998	40	297	517	-350	561	-33	32	-1312	529	0.58	0.61	21	13	0.39	1638	259
2887	1998	40	119	186	-283	358	-10	24	-9	790	0.28	0.27	18	15	0.38	1083	354
2888	1998	40	365	557	-988	423	-58	36	-15	2288	1.45	1.51	21	17	0.43	215	115
2889	1998	40	117	175	-152	250	-13	20	-41	962	0.41	0.39	21	19	0.46	1311	216
3112	1998	40	23	51	-275	131	-6	12	-21	486	0.20	0.21	15	14	0.33	41	92
3086	1999	38	11	19	-270	110	-12	16	-60	471	0.28	0.30	14	10	0.28	469	650
3177	1998	40	21	42	-214	146	-8	14	-33	477	0.18	0.18	15	18	0.38	102	52
3077	1999	40	22	24	-337	323	-25	21	-71	930	0.53	0.55	19	8	0.31	804	1189
3178	1998	40	35	53	-235	106	-8	17	-11	549	0.26	0.24	16	16	0.37	95	78
3081	1999	36	136	180	-66	159	-7	13	-50	1117	0.37	0.38	22	18	0.46	1510	288
3078	1999	33	121	138	-140	789	-11	56	-1315	913	0.60	0.52	25	10	0.39	633	246
3082	1999	36	86	125	-494	67	-10	32	-16	944	0.48	0.44	19	18	0.42	100	184
3080	1999	38	44	94	-640	59	-9	36	-39	734	0.43	0.38	21	14	0.40	1894	217
3079	1999	40	51	82	-327	37	-16	12	-40	812	0.44	0.46	22	14	0.41	1483	517
3085	1999	40	99	216	-1660	65	-8	41	-644	1100	0.56	0.51	18	11	0.34	1774	820
3185	1999	34	168	285	-628	116	-41	43	-20	1716	1.07	1.12	17	16	0.37	104	116
3182	1999	41	150	150	-420	68	-16	26	-20	763	0.48	0.50	18	20	0.44	296	522
3083	1999	32	26	55	-554	52	-9	30	-46	548	0.35	0.30	20	11	0.36	617	285
3076	1999	34	14	33	-391	61	-9	25	-58	452	0.28	0.24	14	10	0.28	1398	356
3075	1999	36	139	221	-400	64	-13	23	-90	519	0.25	0.24	25	15	0.46	234	543
3084	1999	36	n/a	n/a	-511	147	-15	24	-225	1060	0.39	0.41	15	15	0.34	161	242
3184	1999	40	325	348	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0.00	19	16	0.40	2325	1692
3181	1999	40	37	81	-569	71	-12	32	-15	736	0.42	0.38	21	16	0.42	483	216
Average			***114***	***179***	***-455***	***251***	***-14***	***31***	***-348***	***881***	***0.51***	***0.48***	***21***	***15***	***0.40***	***850***	***429***
Pass			***29***	***29***			***27***	***29***	***29***	***28***	***26***	***26***	***30***	***30***	***30***	***30***	***30***
Total Vehicles			***29***	***29***			***29***	***29***	***29***	***29***	***29***	***30***	***30***	***30***	***30***	***30***	***30***
Pass Rate			***100%***	***100%***			***93%***	***100%***	***100%***	***97%***	***90%***	***87%***	***100%***	***100%***	***100%***	***100%***	***100%***

Table B.17 1999 NHTSA Unbelted 208, 5th Percentile Female In Driver Position

Tstno	Make	Model	Year	HIC36	HIC15	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Accel.	Chest Defl.	CTI v2	Femur Left	Femur Right
								AAMA	*AAMA*	*AAMA*	*AAMA*							
				1000	**700**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**	**6800**	**6800**
3113	SATURN	SL1	1999	212	106	-87	278	-6	12	-20	991	0.37	0.37	37	31	0.78	3566	2445
3118	DODGE	INTREPID	1999	N/A	N/A	-1248	111	-80	25	-150	1615	1.52	1.58	57	53	1.26	2667	4778
3119	TOYOTA	TACOMA	1999	351	200	-274	478	-10	19	-490	1328	0.48	0.47	52	51	1.19	5300	6172
2905	FORD	TAURUS	1998	309	202	-270	165	-23	28	-255	1648	0.76	0.79	48	35	0.96	3916	4490
	Average			***290***	***169***	***-470***	***258***	***-30***	***21***	***-229***	***1395***	***0.78***	***0.80***	***49***	***43***	***1.05***	***3862***	***4471***
	Pass			***3***	***3***			***3***	***4***	***4***	***4***	***3***	***3***	***4***	***3***	***2***	***4***	***4***
	Total Vehicles			***3***	***3***			***4***	***4***	***4***	***4***	***4***	***4***	***4***	***4***	***4***	***4***	***4***
	Pass Rate			***100%***	***100%***			***75%***	***100%***	***100%***	***100%***	***75%***	***75%***	***100%***	***75%***	***50%***	***100%***	***100%***

Table B.18 1999 NHTSA Unbelted 208, 5th Percentile Female In Passenger Position

Tstno	Make	Model	Year	HIC36	HIC15	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Accel.	Chest Defl.	CTI v2	Femur Left	Femur Right
								AAMA	*AAMA*	*AAMA*	*AAMA*							
				1000	**700**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**	**6800**	**6800**
3113	SATURN	SL1	1999	396	276	-213	707	-21	35	-67	1802	0.73	0.71	45	15	0.68	3072	3259
3118	DODGE	INTREPID	1999	540	302	-183	738	-29	22	-612	1441	0.62	0.65	62	13	0.85	5078	4093
3119	TOYOTA	TACOMA	1999	401	380	-142	2024	-95	89	-1043	3921	2.65	2.76	42	4	0.52	5974	4931
2905	FORD	TAURUS	1998	282	236	-1239	165	-37	40	-1182	807	0.94	0.97	40	N/A	N/A	4969	5878
	Average			***405***	***299***	***-444***	***909***	***-46***	***46***	***-726***	***1993***	***1.23***	***1.27***	***47***	***11***	***0.68***	***4773***	***4540***
	Pass			***4***	***4***			***3***	***4***	***4***	***3***	***3***	***3***	***3***	***3***	***3***	***4***	***4***
	Total Vehicles			***4***	***4***			***4***	***4***	***4***	***4***	***4***	***4***	***4***	***3***	***3***	***4***	***4***
	Pass Rate			***100%***	***100%***			***75%***	***100%***	***100%***	***75%***	***75%***	***75%***	***75%***	***100%***	***100%***	***100%***	***100%***

Table B.19

1996-1999 Position 1 OOP TESTs With 5th Percentile Female Hybrid III Dummy in Driver Position

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Accel.	Chest Defl.	CTI v2
								AAMA	*AAMA*	*AAMA*	*AAMA*					
				700	**1000**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**
3791	Honda	Accord	1998	N/A	N/A	-1259	58	-54	0	-14	1667	1.28	1.33	15	19	0.39
3787	Toyota	Camry	1998	30	35	-1350	118	-56	5	-4	1537	1.30	1.36	15	19	0.40
3790	Toyota	Camry	1996	70	82	-597	100	-21	6	-31	1586	0.71	0.75	16	19	0.41
3793	Dodge	Neon	1998	32	56	-1743	361	-86	15	-255	1759	1.77	1.83	24	26	0.58
3785	Dodge	Neon	1996	69	105	-2217	36	-103	6	-110	2363	2.12	2.20	28	30	0.67
3783	Ford	Taurus	1998	33	42	-275	1001	-81	20	-4	1446	1.64	1.70	15	17	0.37
3777	Ford	Taurus	1996	136	174	-319	1267	-13	46	-92	2595	1.01	0.99	24	30	0.63
3782	Ford	Explorer	1998	16	23	-89	743	-59	1	-88	1338	1.23	1.28	14	19	0.38
3776	Ford	Explorer	1996	85	104	-211	1802	-145	8	-204	2360	2.79	2.89	25	28	0.61
4002	Saturn	SL	1999	28	39	-144	414	-12	38	-3	89	0.27	0.21	20	26	0.54
4004	Toyota	PU Buck	1999	107	107	-1932	36	-69	0	-17	337	1.16	1.20	22	22	0.51
4005	Ford	Econoline Van	1999	13	20	-1165	63	-59	1	-18	141	0.97	1.00	14	22	0.42
4008	Acura		1999	220	220	-2069	8	-80	13	-7	162	1.32	1.37	18	30	0.55
4009	Ford	Expedition	1999	8	14	-1137	21	-60	0	-8	136	0.98	1.01	11	20	0.36
4011	Dodge	Entrepid Buck	1999	24	24	-848	87	-42	1	-16	172	0.70	0.72	24	27	0.60
	Average			***62***	***75***	***-1024***	***408***	***-62***	***11***	***-58***	***1179***	***1.28***	***1.32***	***19***	***24***	***0.49***
	Pass			***14***	***14***			***3***	***15***	***15***	***12***	***5***	***5***	***15***	***15***	***15***
	Total Vehicles			***14***	***14***			***15***	***15***	***15***	***15***	***15***	***15***	***15***	***15***	***15***
	Pass Rate			***100%***	***100%***			***20%***	***100%***	***100%***	***80%***	***33%***	***33%***	***100%***	***100%***	***100%***

Table B.20

1996-1999 Position 2 OOP TESTs With 5th Percentage Female Hybrid III Dummy in Driver Position

Tstno	Make	Model	year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM Nij	NPRM Nij	Chest Accel.	Chest Defl.	CTI v2
								AAMA	*AAMA*	*AAMA*	*AAMA*					
				700	**1000**			**-39**	**95**	**-2520**	**2070**	**1.00**	**1.00**	**60**	**52**	**1.00**
3792	Honda	Accord	1998	60	117	-613	88	-26	47	-13	1621	0.68	0.70	26	45	0.83
3788	Toyota	Camry	1998	28	41	-978	35	-36	7	-57	1387	0.82	0.85	32	33	0.74
3789	Toyota	Camry	1996	28	35	-940	88	-29	4	-69	1114	0.76	0.79	18	29	0.55
3794	Dodge	Neon	1998	25	34	-578	6	-22	35	-29	774	0.56	0.58	34	34	0.79
3786	Dodge	Neon	1996	160	175	-2553	208	-105	14	-33	3498	2.30	2.39	32	43	0.87
3784	Ford	Taurus	1998	14	17	-243	628	-48	12	-10	1143	1.00	1.04	28	39	0.77
3778	Ford	Taurus	1996	NA	NA	-185	783	-52	15	-117	1112	1.14	1.18	21	44	0.76
3779	Ford	Explorer	1998	8	10	-77	801	-55	7	-74	815	1.08	1.12	14	22	0.42
3780	Ford	Explorer	1996	32	33	-43	1552	-124	3	-16	1433	2.22	2.30	36	40	0.88
4000	Ford	Econoline Van	1999	8	14	-595	171	-18	10	-12	64	0.29	0.30	25	33	0.67
4001	Saturn	SL	1999	61	71	-747	117	-20	57	-13	103	0.37	0.36	23	36	0.69
4003	Toyota	PU Buck	1999	59	59	-864	19	-39	9	-18	204	0.65	0.67	30	31	0.71
4006	Dodge	Entrepid Buck	1999	10	15	-730	26	-35	4	-43	88	0.57	0.59	40	47	1.01
4007	Acura		1999	40	43	-1140	21	-38	18	-11	116	0.62	0.64	26	29	0.64
4010	Ford	Expedition	1999	9	15	-679	49	-21	12	-10	72	0.34	0.35	32	37	0.80
	Average			***39***	***48***	***-731***	***306***	***-45***	***17***	***-35***	***903***	***0.89***	***0.92***	***28***	***36***	***0.74***
	Pass			***14***	***14***			***10***	***15***	***15***	***14***	***10***	***10***	***15***	***15***	***14***
	Total Vehicles			***14***	***14***			***15***	***15***	***15***	***15***	***15***	***15***	***15***	***15***	***15***
	Pass Rate			***100%***	***100%***			***67%***	***100%***	***100%***	***93%***	***67%***	***67%***	***100%***	***100%***	***93%***

Table B.21

1996 - 1999 Position 1 OOP Tests With Six Year Old Hybrid III Dummy at 0 Inches.

Tstno	Make	Model	Year	Pos.	Dist.	HIC15	HIC36	Neg.Shear	Pos Shear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Defl.	CTI v2
										AAMA	*AAMA*	*AAMA*	*AAMA*					
						700	1000			-24	60	-1820	1490	1.00	1.00	60	40	1.00
4045*	Acura	RL	1999	1	0	101	135	715	402	-38	7	-249	1213	1.26	1.23	19	11	0.38
4046+	Acura	RL	1999	1	0	87	129	366	451	-23	4	-113	1223	0.91	0.88	19	7	0.32
4048	Dodge	Intrepid	1999	1	0	149	149	2092	166	-88	0	-61	3479	2.78	2.71	59	42	1.31
4039	Ford	Econoline	1999	1	0	428	428	NA	NA	NA	NA	NA	NA	2.66	2.58	50	45	1.26
4044	Ford	Expedition	1999	1	0	42	75	823	300	-25	3	-88	1296	1.02	0.99	39	50	1.21
4037	Saturn	N/A	1999	1	0	35	40	541	265	-28	5	-97	1799	0.89	0.87	23	44	0.95
4038	Toyota	Tacoma	1999	1	0	145	145	2477	98	-98	0	-39	3509	3.31	3.22	18	22	0.54
3760	HONDA	ACCORD	1998	1	0	132	188	1339	418	-49	12	-1899	2591	2.05	1.99	37	40	1.04
3754	TOYOTA	CAMRY	1998	1	0	213	299	809	1484	-109	47	-54	3351	3.64	3.54	33	11	0.54
3771	DODGE	CARAVAN	1998	1	0	493	1029	3443	6	-87	22	-6	3971	3.30	3.21	31	51	1.13
3765	FORD	EXPLORER	1998	1	0	210	335	4	3214	-186	0	-6	4612	5.91	5.75	50	50	1.34
3744	DODGE	NEON	1998	1	0	172	310	2863	449	-72	5	-50	3111	2.65	2.58	22	42	0.90
3739	FORD	TAURUS	1998	1	0	1854	1854	1733	1557	-64	7	-3	7352	2.81	2.72	64	50	1.50
3757	TOYOTA	CAMRY	1996	1	0	1020	1687	1039	4309	-275	60	-477	5640	8.67	8.44	65	45	1.43
3768	DODGE	CARAVAN	1996	1	0	1207	1221	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	83	50	N/A
3742	FORD	EXPLORER	1996	1	0	276	276	2660	42	-84	0	-272	6871	2.91	2.81	43	63	1.46
3774	FORD	EXPLORER	1996	1	0	278	504	3109	46	-92	11	-482	4618	3.58	3.47	38	60	1.36
3747	DODGE	NEON	1996	1	0	377	789	3234	501	-87	4	-37	4628	3.13	3.04	36	44	1.08
3736	FORD	TAURUS	1996	1	0	2471	2471	3052	1242	-42	211	-210	9489	3.69	3.50	54	28	1.04
	Average					*510*	*635*	*1782*	*879*	*-85*	*23*	*-244*	*4044*	*3.07*	*2.97*	*41*	*40*	*1.04*
	Pass					*15*	*14*			*1*	*16*	*16*	*3*	*2*	*3*	*16*	*5*	*6*
	Total Vehicles					*19*	*19*			*17*	*17*	*17*	*17*	*18*	*18*	*19*	*19*	*18*
	Pass Rate					*79%*	*74%*			*6%*	*94%*	*94%*	*18%*	*11%*	*17%*	*84%*	*26%*	*33%*

+ First Stage Only

** Both Stages with 40 ms delay.*

Table B.22

1996 - 1998 Position 1 OOP Tests With Six Year Old Hybrid III Dummy at 4 Inches

Tstno	Make	Model	Year	Pos.	Dist.	HIC15	HIC36	Neg Shear	Pos Shear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Defl.	CTI v2
										AAMA	*AAMA*	*AAMA*	*AAMA*					
						700	1000			-24	60	-1820	1490	1.00	1.00	60	40	1.00
3761	HONDA	ACCORD	1998	1	4	142	228	1026	295	-44	2	-17	1721	1.53	1.49	28	27	0.74
3755	TOYOTA	CAMRY	1998	1	4	1436	2217	1459	575	-24	104	-890	2186	1.27	1.23	38	7	0.54
3772	DODGE	CARAVAN	1998	1	4	91	180	27	1011	-3	58	-344	791	0.69	0.54	33	25	0.76
3766	FORD	EXPLORER	1998	1	4	16	30	38	80	-11	5	-19	796	0.40	0.39	17	35	0.74
3745	DODGE	NEON	1998	1	4	176	278	1887	1274	-66	6	-22	2456	2.39	2.33	28	22	0.65
3740	FORD	TAURUS	1998	1	4	1431	1431	1575	1241	-69	32	-46	3542	2.21	2.15	33	15	0.60
3758	TOYOTA	CAMRY	1996	1	4	1131	1410	1402	2552	-193	87	-118	5251	6.22	6.05	55	39	1.21
3769	DODGE	CARAVAN	1996	1	4	697	1559	589	2179	-32	73	-893	2069	1.36	1.32	51	50	1.34
3743	FORD	EXPLORER	1996	1	4	300	476	2154	371	-64	6	-6	3464	2.62	2.54	34	42	1.03
3763	FORD	EXPLORER	1996	1	4	375	660	179	467	-44	11	-5	2668	1.67	1.62	54	53	1.43
3748	DODGE	NEON	1996	1	4	236	401	2667	438	-79	6	-28	3256	3.19	3.10	27	30	0.78
3737	FORD	TAURUS	1996	1	4	525	525	1174	757	-62	7	-536	3137	2.09	2.03	18	10	0.36
	Average					*546*	*783*	*1182*	*937*	*-58*	*33*	*-244*	*2612*	*2.14*	*2.06*	*35*	*30*	*0.85*
	Pass					*9*	*8*			*3*	*9*	*12*	*2*	*2*	*2*	*12*	*9*	*9*
	Total Vehicles					*12*	*12*			*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*	*12*
	Pass Rate					*75%*	*67%*			*25%*	*75%*	*100%*	*17%*	*17%*	*17%*	*100%*	*75%*	*75%*

Table B.23 1996 - 1998 Position 1 OOP Tests With Six Year Old Hybrid III Dummy at 8 Inches

Tstno	Make	Model	Year	Pos.	Dist.	HIC15	HIC36	Neg Shear	Pos Shear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Defl.	CTI v2
										AAMA	***AAMA***	***AAMA***	***AAMA***					
						700	**1000**			**-24**	**60**	**-1820**	**1490**	**1.00**	**1.00**	**60**	**40**	**1.00**
3762	HONDA	ACCORD	1998	1	8	66	138	270	284	-22	4	-24	1205	0.92	0.89	16	20	0.49
3756	TOYOTA	CAMRY	1998	1	8	395	847	183	1194	-75	7	-2929	4220	2.31	2.25	28	30	0.79
3773	DODGE	CARAVAN	1998	1	8	77	91	3	1044	-0	62	-390	621	0.87	0.69	30	13	0.54
3767	FORD	EXPLORE	1998	1	8	73	73	835	7	-0	69	-546	605	0.86	0.67	20	12	0.41
3746	DODGE	NEON	1998	1	8	495	495	219	843	-19	29	-160	977	0.70	0.68	16	10	0.34
3741	FORD	TAURUS	1998	1	8	250	306	53	985	-14	23	-193	1101	0.60	0.59	20	9	0.36
3759	TOYOTA	CAMRY	1996	1	8	656	876	1910	147	-8	174	-3453	1487	3.09	2.57	42	N/A	N/A
3770	DODGE	CARAVAN	1996	1	8	480	485	189	1415	-16	67	-583	1152	1.04	0.87	54	33	1.11
3764	FORD	EXPLORE	1996	1	8	111	202	570	35	-10	69	-327	1404	0.86	0.68	26	40	0.91
3753	DODGE	NEON	1996	1	8	873	873	1465	1782	-62	32	-102	2344	2.35	2.28	25	24	0.66
3738	FORD	TAURUS	1996	1	8	321	351	63	643	-9	32	-869	731	0.62	0.52	21	5	0.32
	Average					***345***	***431***	***524***	***762***	***-21***	***52***	***-871***	***1441***	***1.29***	***1.15***	***27***	***20***	***0.59***
	Pass					***10***	***11***			***9***	***6***	***9***	***9***	***7***	***8***	***11***	***9***	***9***
	Total Vehicles					***11***	***11***			***11***	***11***	***11***	***11***	***11***	***11***	***11***	***10***	***10***
	Pass Rate					***91%***	***100%***			***82%***	***55%***	***82%***	***82%***	***64%***	***73%***	***100%***	***90%***	***90%***

Table B.24

1999 Position 2 OOP Tests With Six Year Old Hybrid III Dummy at 0 Inches.

Tstno	Make	Model	Year	Pos.	Dist.	HIC15	HIC36	Neg Shear	Pos. Shear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Defl.	CTI v2
										AAMA	*AAMA*	*AAMA*	*AAMA*					
						700	1000			-24	60	-1820	1490	1.00	1.00	60.0	40.0	1.00
4035*	Acura	RL	1999	2	0	101	162	98	471	-11	38	-1482	1125	0.83	0.73	17.7	3.0	0.24
4047+	Acura	RL	1999	2	0	113	149	190	520	-17	42	-1497	1143	0.94	0.81	16.0	9.0	0.32
4042	Dodge	Intrepid	1999	2	0	627	627	2259	1863	-91	52	-231	4834	3.27	3.18	68.8	39.7	1.38
4043	Ford	Expedition	1999	2	0	131	142	1943	285	-70	4	-64	3436	2.27	2.20	85.5	45.0	1.65
4040	Ford	Econoline	1999	2	0	429	429	1914	2262	-54	95	-144	2820	2.22	2.16	65.0	34.3	1.26
4036	Saturn	N/A	1999	2	0	76	76	1508	74	-60	0	-36	2548	1.97	1.92	44.6	43.4	1.17
4041	Toyota	Tacoma	1999	2	0	246	246	1805	477	-71	7	-359	4048	2.54	2.47	41.0	18.3	0.74
	Average					*246*	*262*	*1388*	*850*	*-53*	*34*	*-545*	*2850*	*2.01*	*1.92*	*48*	*28*	*0.97*
	Pass					*7*	*7*			*2*	*6*	*7*	*2*	*2*	*2*	*4*	*5*	*3*
	Total Vehicles					*7*	*7*			*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*	*7*
	Pass Rate					*100%*	*100%*			*29%*	*86%*	*100%*	*29%*	*29%*	*29%*	*57%*	*71%*	*43%*

+ First Stage Only

** Both Stages with 40 ms delay.*

Table B.25

Six Year Old Hybrid III Dummy Crash Reconstruction

Tstno	Make	Model	Year	HIC15	HIC36	NegShear	PosShear	Extension	Flexion	Compression	Tension	SNPRM NIJ	NPRM NIJ	Chest Accel.	Chest Defl.	CTI V2	MAIS
								AAMA	***AAMA***	***AAMA***	***AAMA***						
				700	**1000**			**-24**	**60**	**-1820**	**1490**	**1.00**	**1.00**	**60**	**40**	**1.00**	
2513	VOLVO	850	1993	1034	1034	-4512	268	-134	10	-876	6892	5.19	5.04	17	22	0.53	5
2778	CHEVROLET	MONTE CARLO	1995	1866	1866	-1344	3883	-246	78	-825	5534	8.24	8.01	34	8	0.51	3
2779	TOYOTA	COROLLA	1994	261	302	-507	412	-20	32	-1030	904	0.78	0.76	47	9	0.66	1
2780	FORD	ESCORT	1995	54	100	-301	439	-24	14	-940	879	0.85	0.83	29	4	0.38	1
2786	DODGE	INTREPID	1993	420	776	-272	2932	-177	9	-1170	3374	5.58	5.44	50	32	1.06	5
	Average			***727***	***815***	***-1387***	***1587***	***-120***	***28***	***-968***	***3516***	***4.13***	***4.02***	***35***	***15***	***0.63***	
	Pass			***3***	***3***			***2***	***4***	***5***	***2***	***2***	***2***	***5***	***5***	***4***	
	Total Vehicles			***5***	***5***			***5***	***5***	***5***	***5***	***5***	***5***	***5***	***5***	***5***	
	Pass Rate			***60%***	***60%***			***40%***	***80%***	***100%***	***40%***	***40%***	***40%***	***100%***	***100%***	***80%***	

Appendix C

Application of Proposed Nij Neck Injury Criteria to Available NHTSA Test Data

Calculations of Nij were made for a wide variety of test data available in the NHTSA database. Analyses were conducted for data from NCAP tests for both drivers and passengers, FMVSS 208 unbelted 30 mph rigid barrier crash tests with 1998 and 1999 model year vehicles, 25 mph offset tests with 5th percentile female drivers and passengers, 30 mph rigid barrier tests with 5th percentile female drivers, and out-of-position tests for 6 year old and 5th percentile female dummies. Results from these tests are presented here and are included in tabular format in Appendix B.

Comparisons between the Nij combined neck injury criteria and the suggested performance limits submitted by the AAMA for out-of-position occupants are shown for the different types of data analyzed. Two points are plotted for each test, corresponding to each set of injury criteria. The point corresponding to the Nij criteria, labeled with a **Ž**, is located at the values of axial load (F_Z) and flexion/extension bending moment (M_Y) which yield the maximum value for Nij. It is important to realize that these values for F_Z and M_Y are concurrent in time and are not necessarily equal to the maxima during the entire event. The point corresponding to the AAMA proposed values for out-of-position, labeled with a •, is located at the overall maximum values of axial load and bending moment. The two values that determine this point are independent of time, and do not necessarily occur at the same time. It is also important to notice that shear load is not included on this plot.

Since the AAMA independent point always represents the overall maxima while the Nij point does not, it is impossible for the Nij point to be located further from the origin than the AAMA independent point. To help identify the matched sets of points, they have been joined together by a line. If the line segment is short, and the points lie essentially on top of one another, it implies that the Nij maximum value occurs close to the same time as the independent maxima. If the line segment is long, this indicates that the Nij maximum occurs at a much different time than the independent maxima.

The thick broken rectangle in the figures represents the AAMA proposal for neck injury criteria for axial load and bending moment in out-of-position testing. The AAMA's suggested independent limits for tension, compression, flexion and extension which are the same as those used currently for the 50th percentile male in the alternative sled test option, with the exception of the extension value. The AAMA's proposed a limit in extension for the 50th percentile male is 77 N-m for out-of-position testing and 96 N-m for in-position testing, which are higher than the 57 N-m used currently for the sled test. The AAMA reasoned that for in-position testing because the occupant would be aware of the crash and would tense the neck muscles, the performance limits could be raised for tension and extension. However, the agency has determined that it is not prudent to raise these limits because not all occupants, especially passengers, may be aware of an impending crash and furthermore because there was little scientific data to support the large increase in the extension tolerance to 96 N-m. Thus, the limit of 77 N-m is plotted for the extension limit for the 50th percentile male. The solid "kite" shape represents the Nij = 1.0 criteria, corresponding to a 22% risk of an AIS$3 injury. The vertices for each region shown on the plot are scaled for each different dummy size. Data points lying within either the box or kite are considered to pass the corresponding criteria.

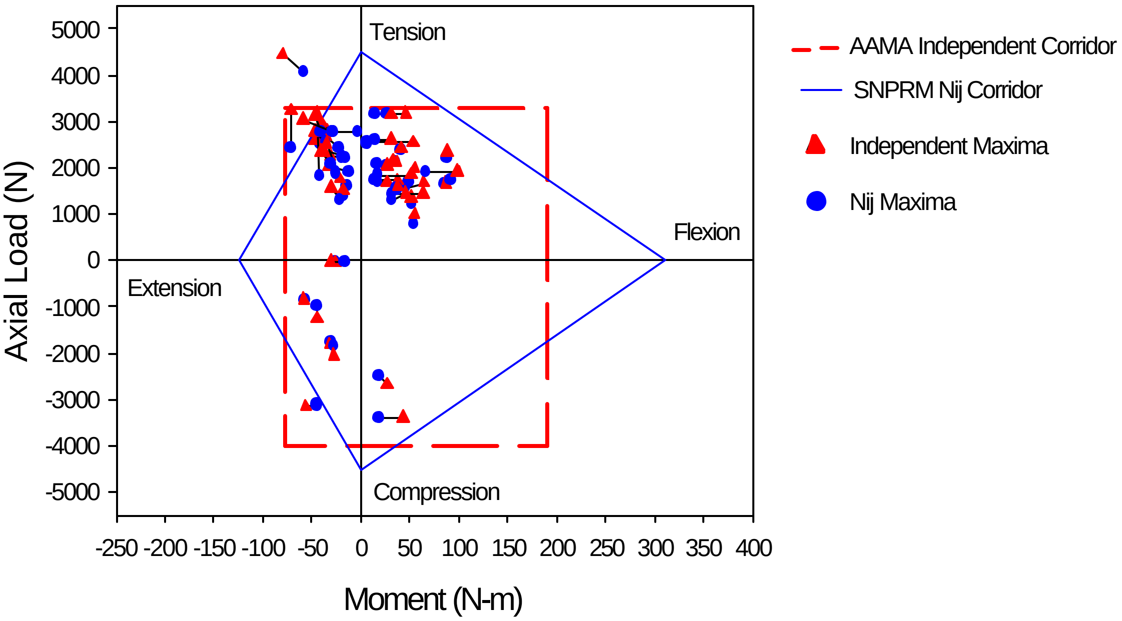

Figure C-1. **Comparison of Neck Injury Criteria for 1998 NCAP Tests with Belted 50th Percentile Male ATD in Driver Position.**

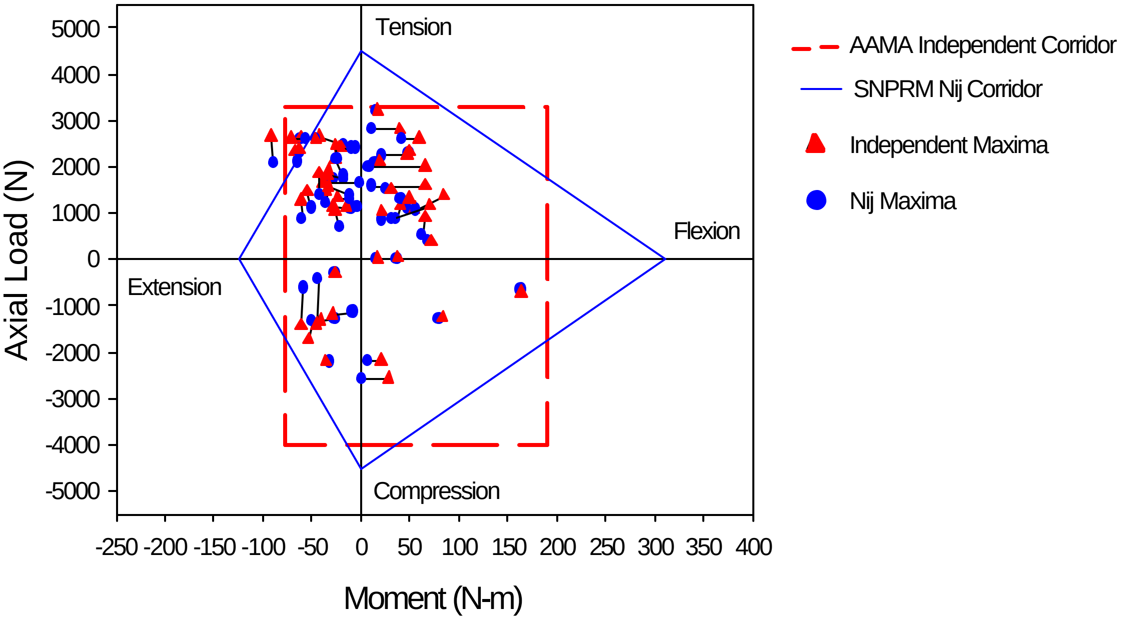

Figure C-2. **Comparison of Neck Injury Criteria for 1998 NCAP Tests with Belted 50th Percentile Male ATD in the Passenger Position.**

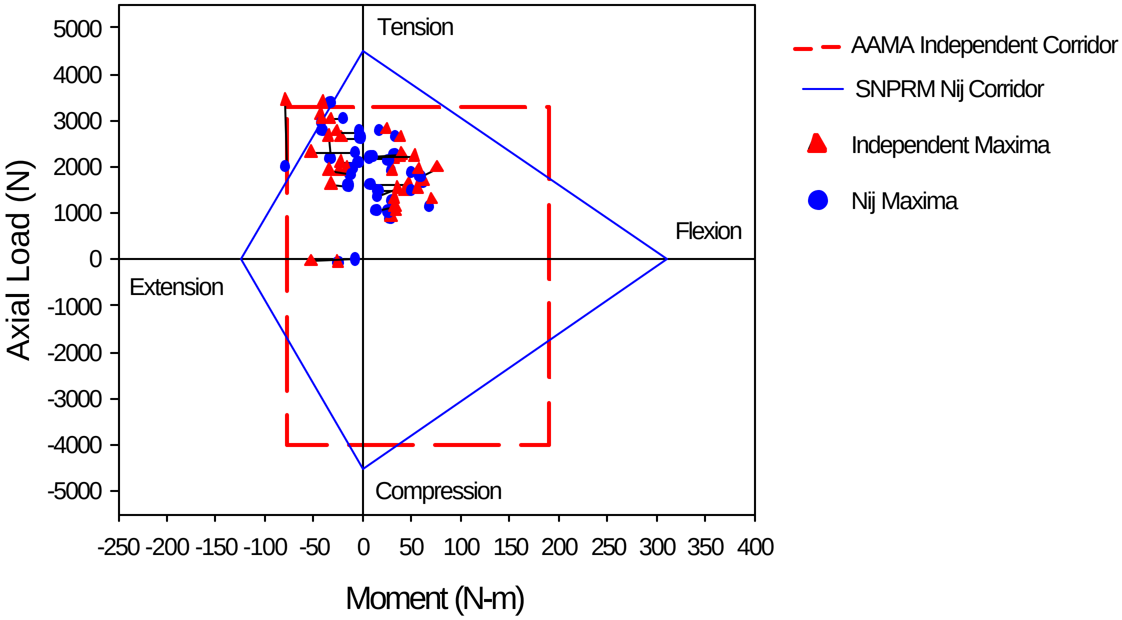

Figure C-3. **Comparison of Neck Injury Criteria for 1999 NCAP Tests with Belted 50th Percentile Male ATD in the Driver Position.**

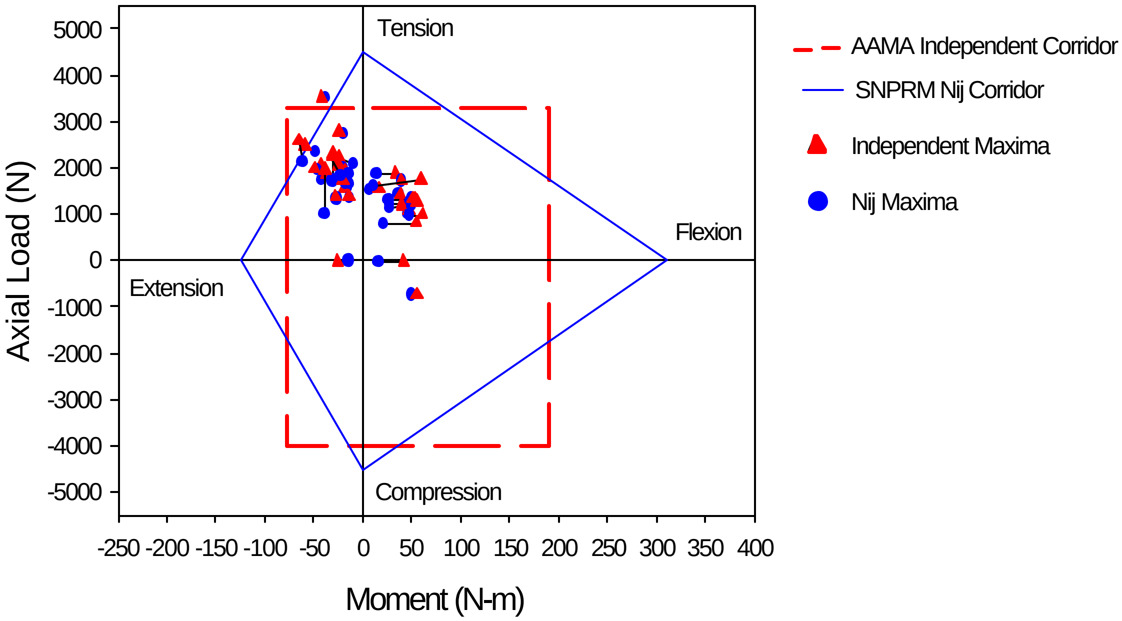

Figure C-4. **Comparison of Neck Injury Criteria for 1999 NCAP Tests with Belted 50th Percentile Male ATD in the Passenger Position.**

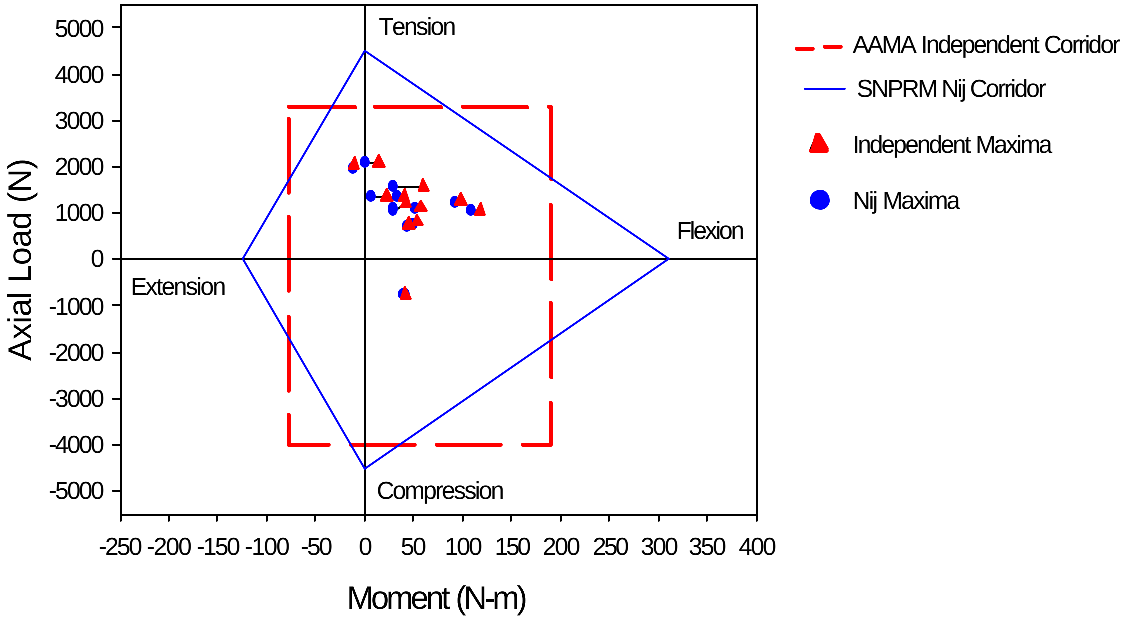

Figure C-5. **Comparison of Neck Injury Criteria for 1998-1999 Unbelted 208 Barrier Crash Tests for Vehicles using 50th Percentile Male ATD in the Driver Position.**

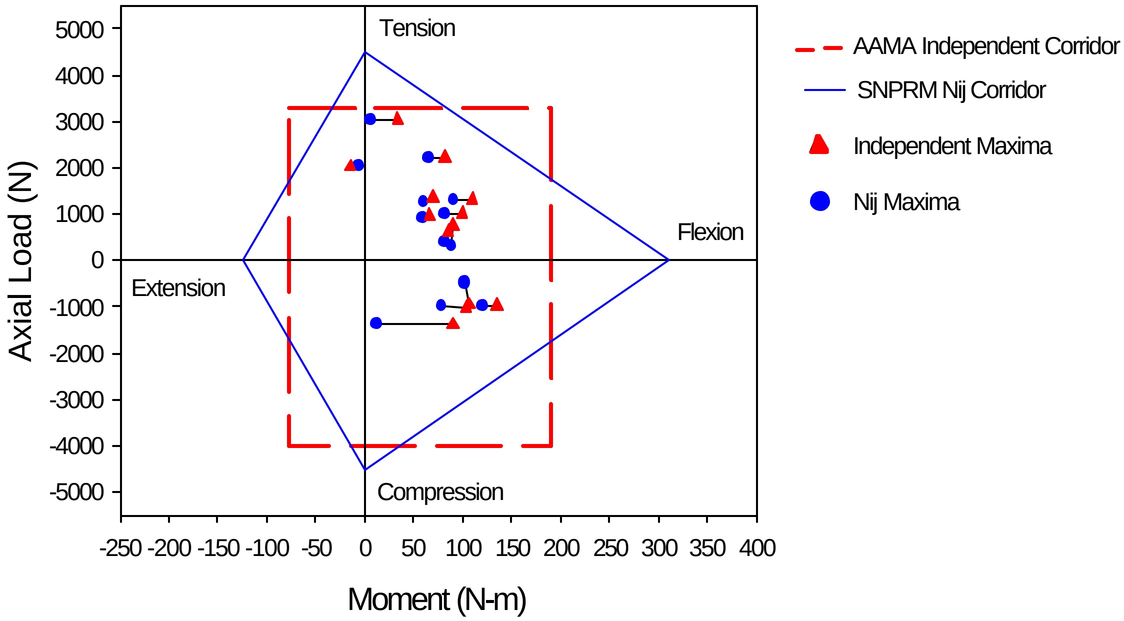

Figure C-6. **Comparison of Neck Injury Criteria for 1998-1999 Unbelted 208 Barrier Crash Tests for Vehicles using 50th Percentile Male ATD in the Passenger Position.**

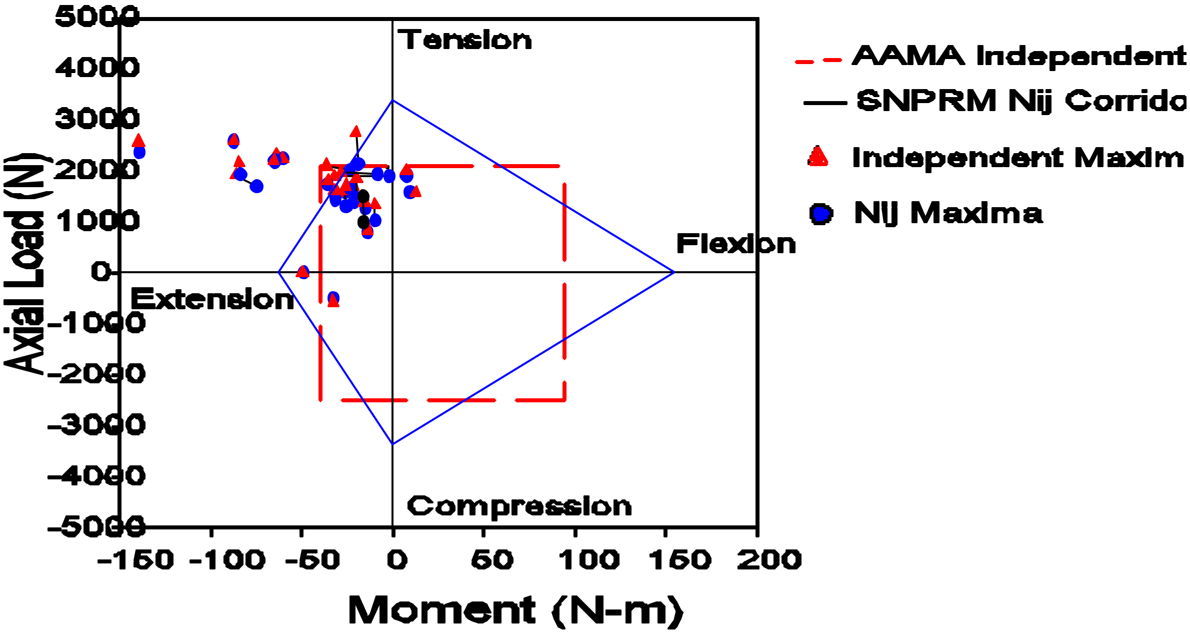

Figure C-7. Comparison of Neck Injury Criteria for Transport Canada 48 KMPH for 1998-1999 Vehicles Belted with 5th Percentile Female ATD in the Driver Position

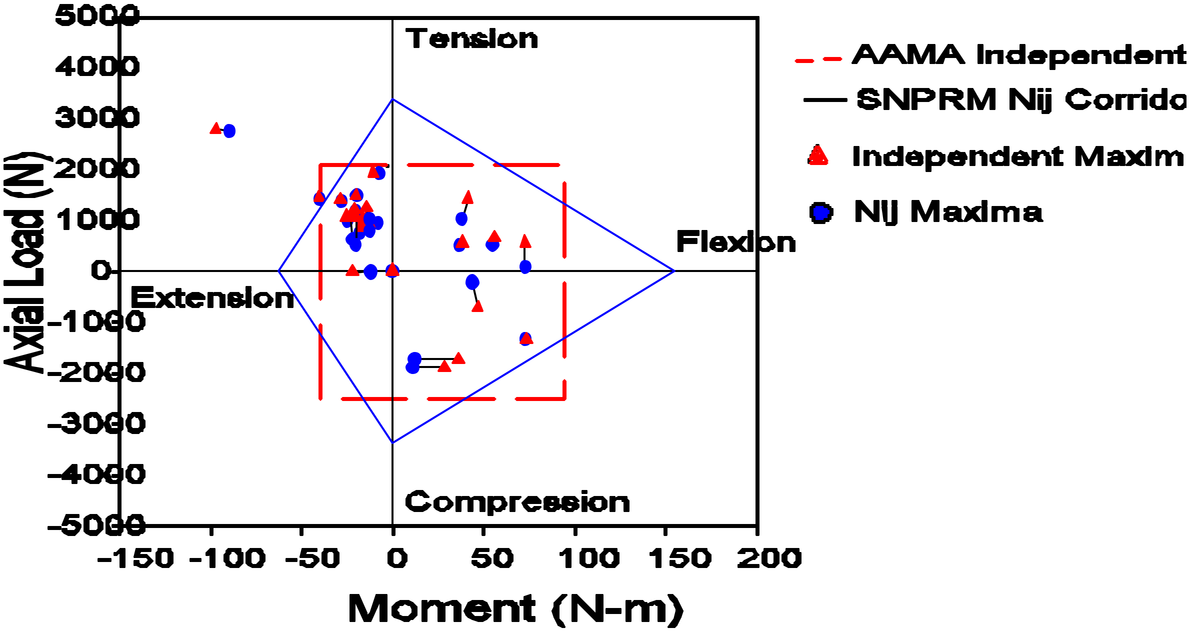

Figure C-8. Comparison of Neck Injury Criteria for Transport Canada 48 KMPH for 1998-1999 Vehicles Belted with 5th Percentile Female ATD in the Passenger Position.

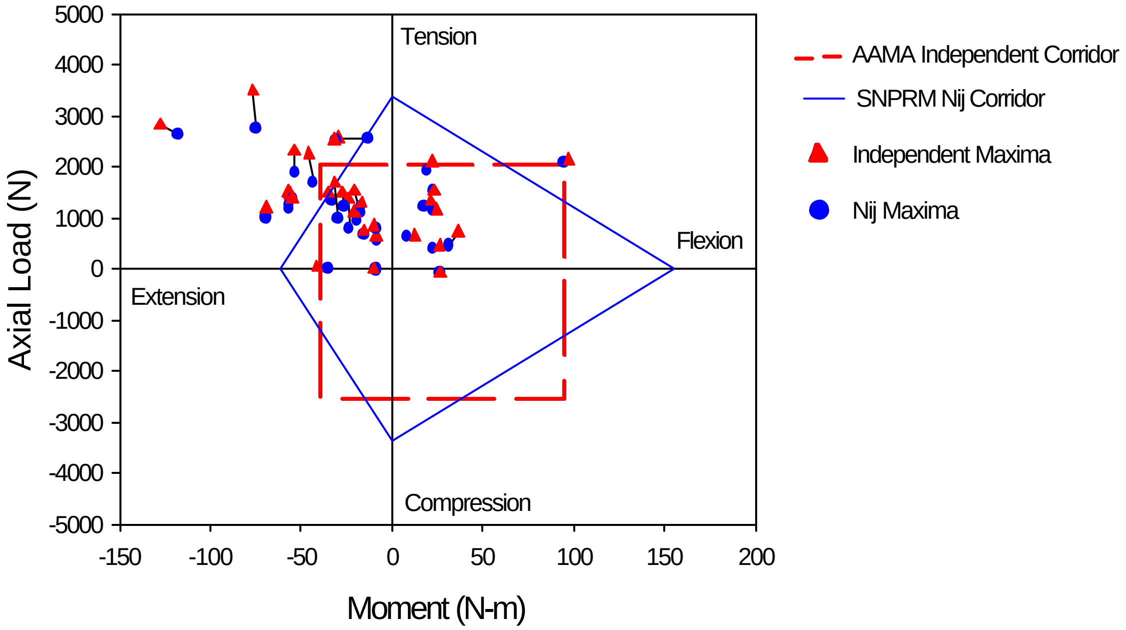

Figure C-9. **Comparison of Neck Injury Criteria for Transport Canada 40% Offset Tests for 1998-1999 Vehicles Belted with 5th Percentile Female ATD in the Driver Position.**

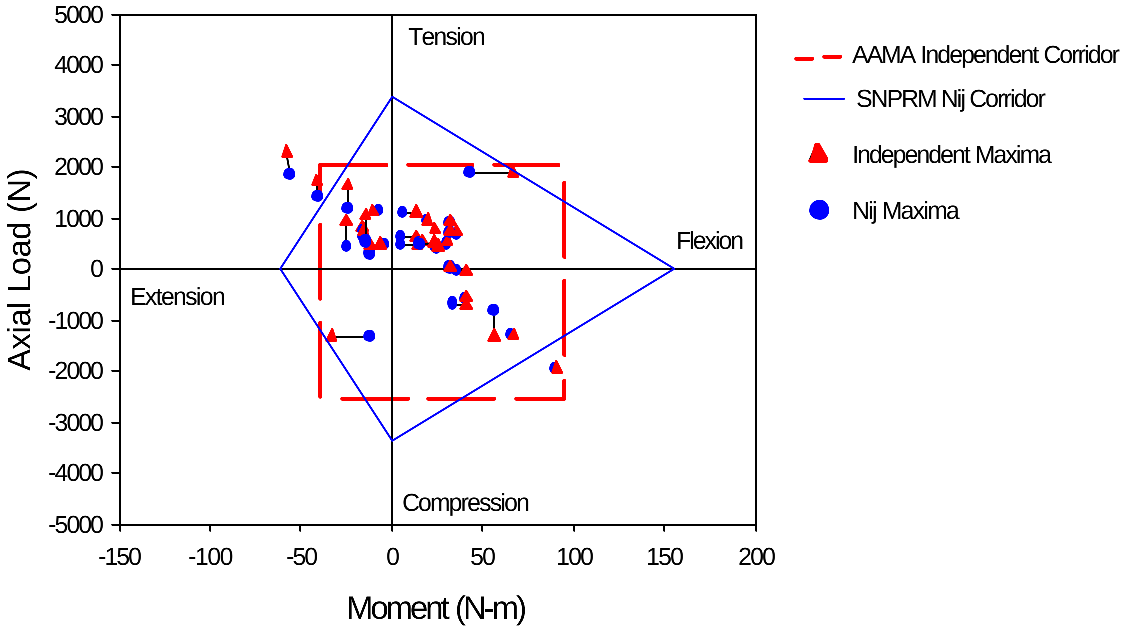

Figure C-10. **Comparison of Neck Injury Criteria for Transport Canada 40% Offset Tests for 1998-1999 Vehicles Belted with 5th Percentile Female ATD in the Passenger Position.**

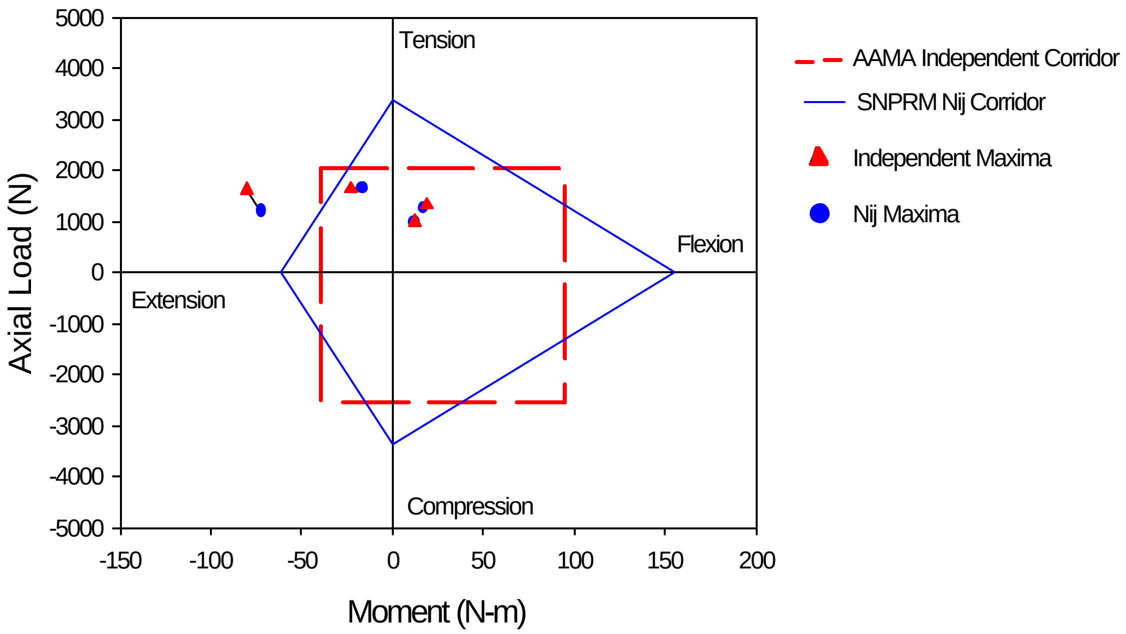

Figure C-11. Comparison of Neck Injury Criteria for 1999 NHTSA Unbelted 208 with 5th Percentile Female ATD in the Driver Position.

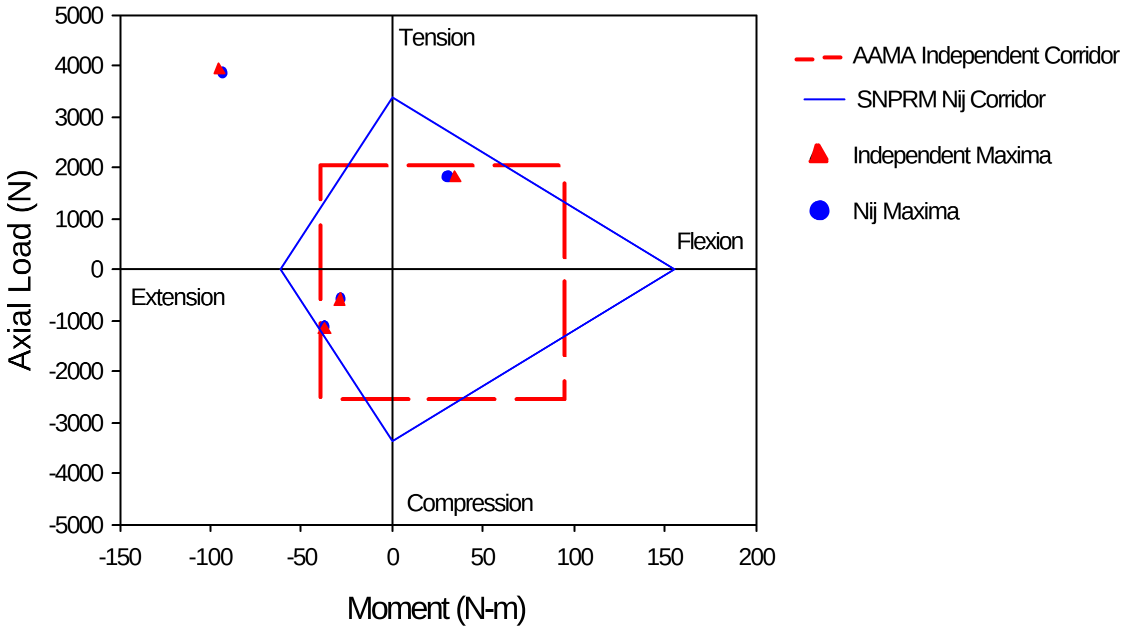

Figure C-12. Comparison of Neck Injury Criteria for 1999 NHTSA Unbelted 208 with 5th Percentile Female ATD in the Passenger Position.

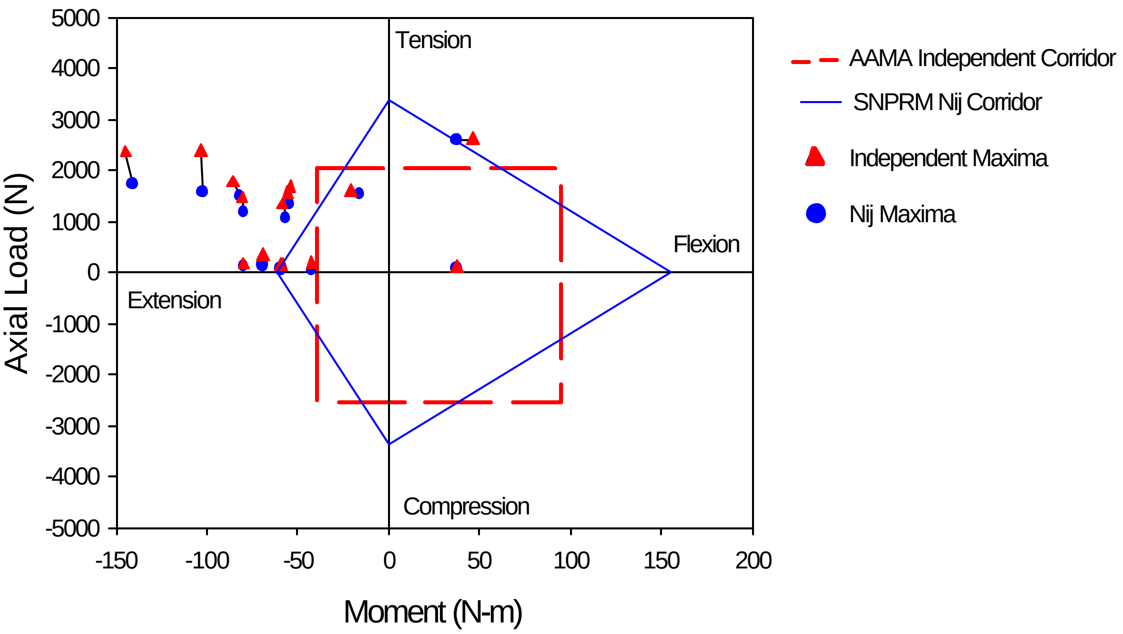

Figure C-13. **Comparison of Neck Injury Criteria for Out-of-Position Tests with 5th Percentile Female Hybrid III Dummy in Position-1 Driver Position.**

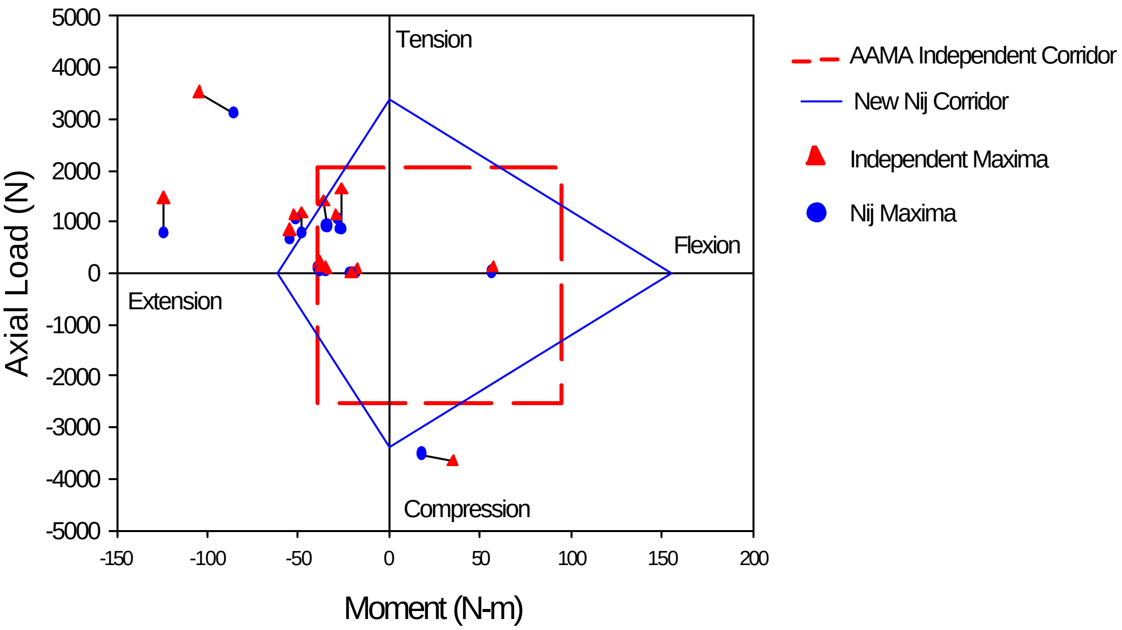

Figure C-14. **Comparison of Neck Injury Criteria for Out-of-Position Tests with 5th Percentile Female Hybrid III Dummy in Position-2 Driver Position.**

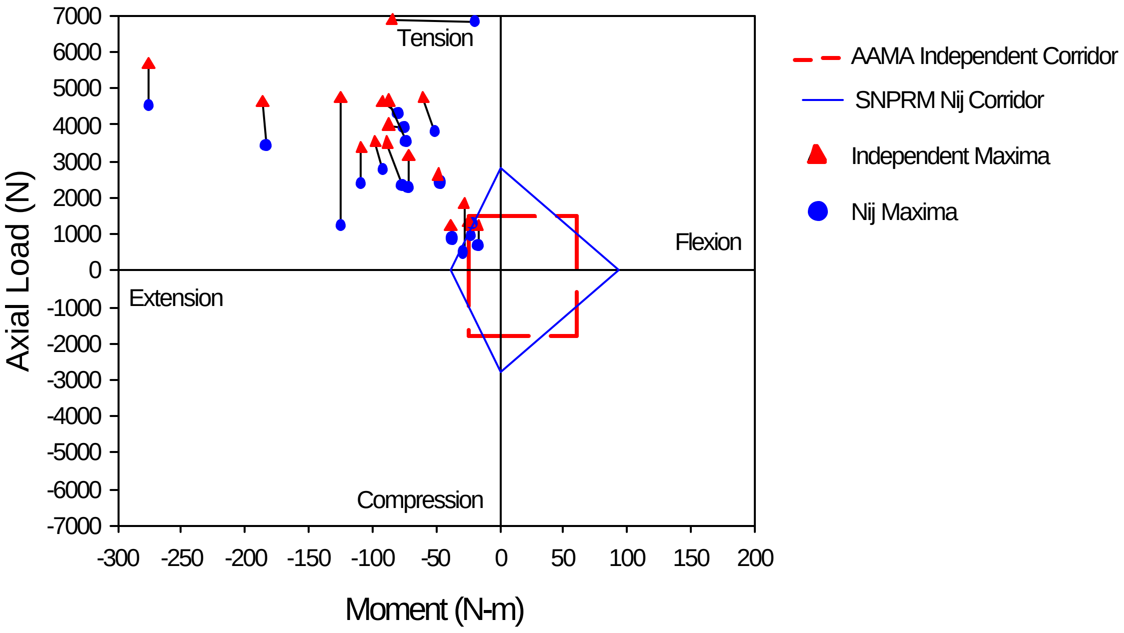

Figure C-15. **Comparison of Neck Injury Criteria for Out-of-Position Tests for 1996-1999 with Hybrid III 6YO Dummy in Position-1 at 0 inches**

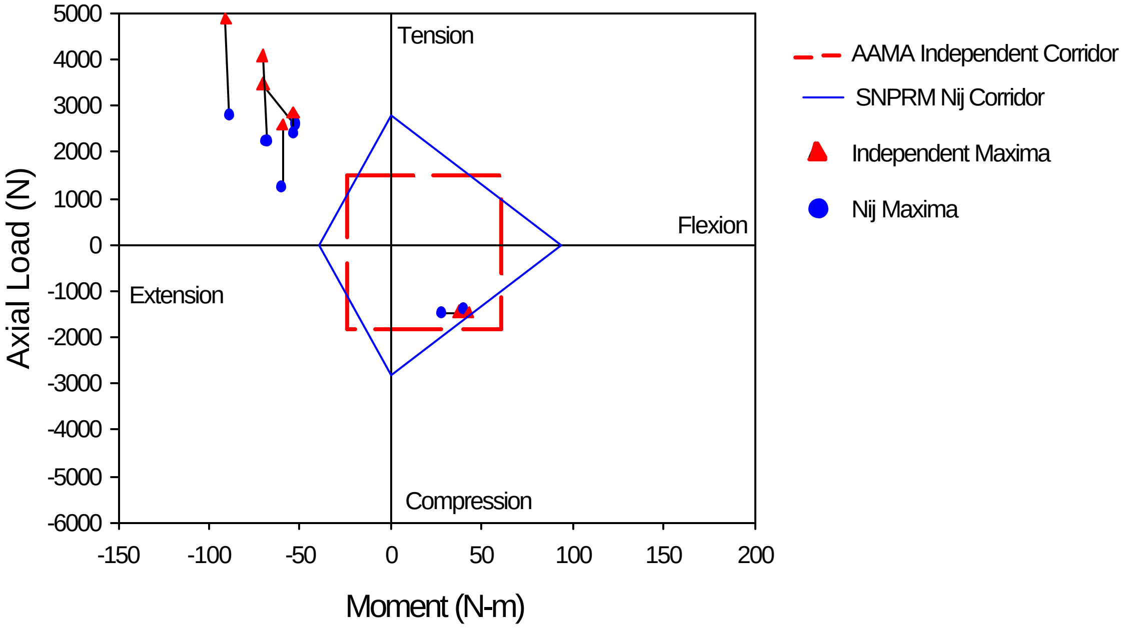

Figure C-16. **Comparison of Neck Injury Criteria for Out-of-Position Tests for 1996-1999 with Hybrid III 6YO Dummy in Position-2 at 0 inches**

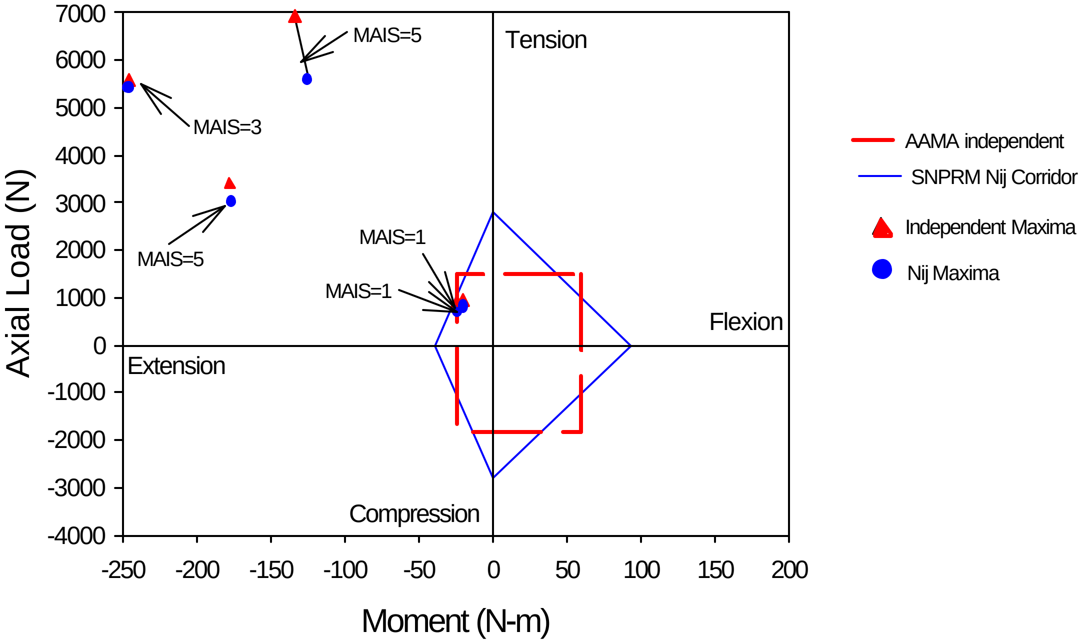

Figure C-17. Comparison of Neck Injury Criteria for Hybrid III 6YO Dummy Data from NASS and SCI Case Reconstructions.

Appendix D

Application of Proposed Thoracic Injury Criteria to Available NHTSA Test Data

The thoracic injury criteria were calculated for a wide variety of tests available in the NHTSA database. Analyses were conducted for data from 30 mph FMVSS No. 208 compliance tests, 35 mph NCAP tests, 48 kmph rigid barrier and 40 kmph offset tests with 5th percentile female dummies, and out-of-position test with the 6 year-old, and 5th percentile female dummies. The results are presented in a tablular form in Appendix B.

In the following figures, the 3 msec clip chest acceleration and the maximum sternal chest deflection measured by the dummy are plotted on the x and y axes, respectively. The solid lines represent the limits for the two proposed thoracic injury critieria. These are (1) the 3 ms clip acceleration is less than or equal to Ac and (2) the maximum chest deflection is less than or equal to Dc, where Ac and Dc are listed in Table D.1.

Table D.1. Scaled Deflection and Acceleration Values for Various Occupant Sizes

Value	Mid-Sized Male	Small Female	6 Year Old	3 Year Old	12 Month Old
Chest Deflection Limit for Thoracic Injury (Dc)	63 mm (2.5 in)	52 mm (2.0 in)	40 mm (1.6 in)	34 mm (1.3 in)	30 mm** (1.2 in)
Chest Acceleration Limit for Thoracic Injury Criteria (Ac)	60	60*	60	55^{+}	50^{*+}

* Although geometric scaling alone would predict higher A_c values for females, it is believed that lower bone mineral density would offset this effect. Therefore, the acceleration tolerance values for small females are kept the same as for mid-sized males.

** The CRABI 12 month old dummy is currently not capable of measuring chest deflection.

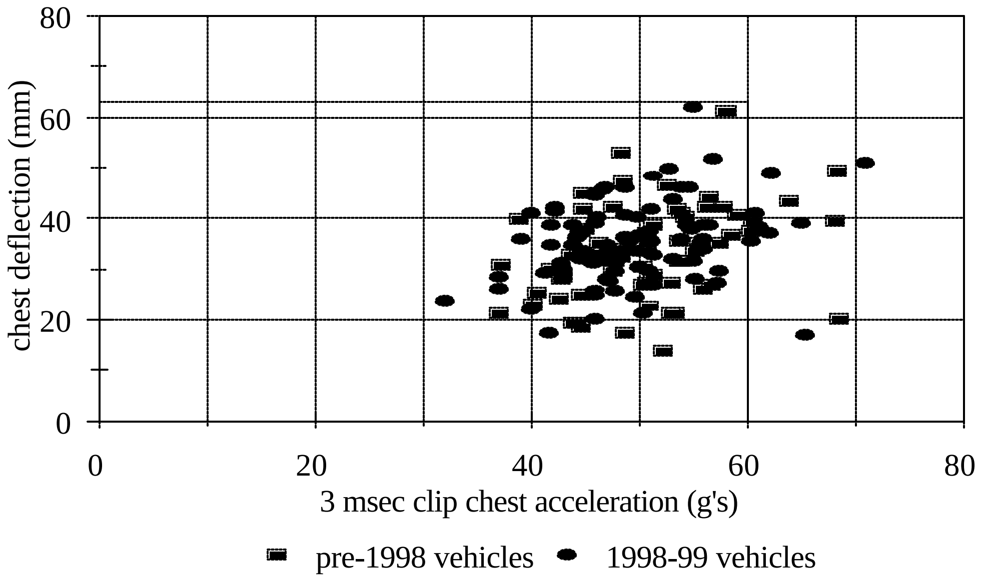

Figure D-1. 1996 to 1999 NCAP crash tests with the ATD in the driver position and performance limits for chest acceleration and deflection for the 50th percentile male dummy. The passing rate for the dummy in the driver position is 90%.

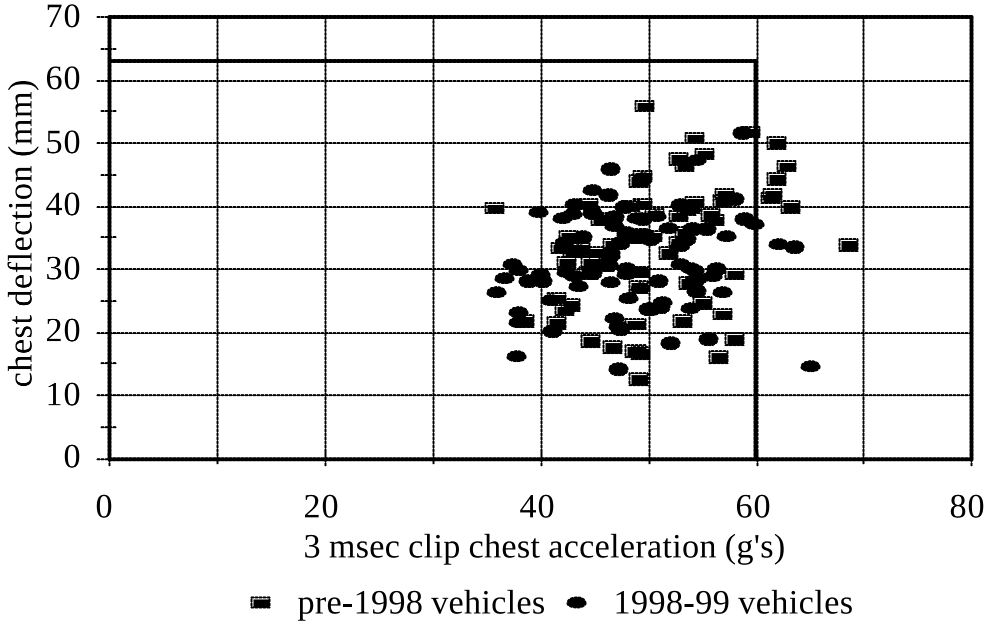

Figure D-2. 1996 to 1999 NCAP crash tests with the ATD in the passenger position and performance limits for chest acceleration and deflection for the 50th percentile male dummy. The passing rate for the dummy in the driver position is 93%.

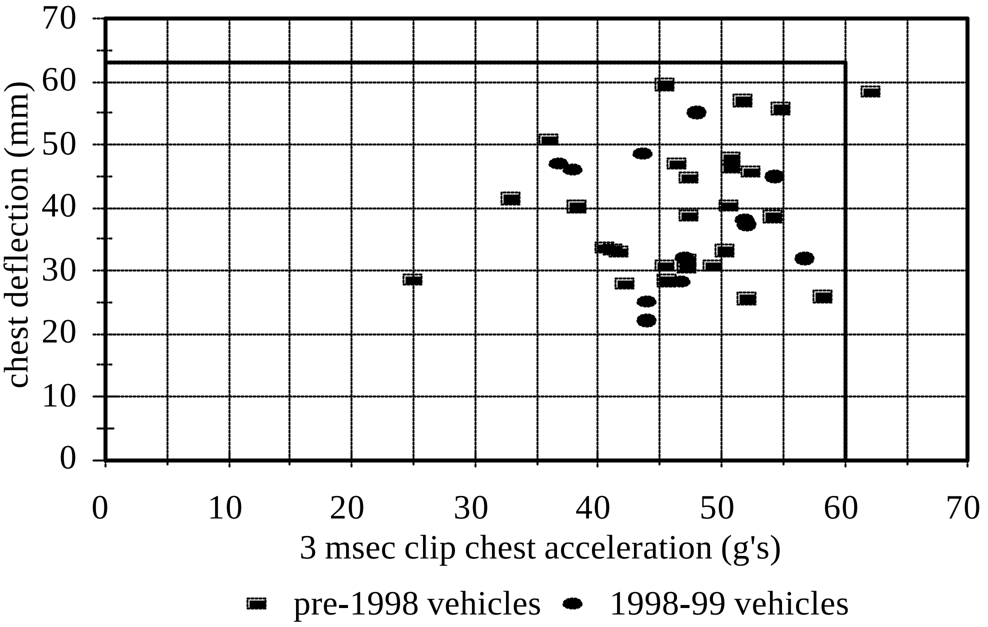

Figure D-3. **1996 to 1999 FMVSS 208 crash tests with the ATD in the driver position and performance limits for chest acceleration and deflection for the 50th percentile male dummy.** The passing rate for the dummy in the driver position is 98%.

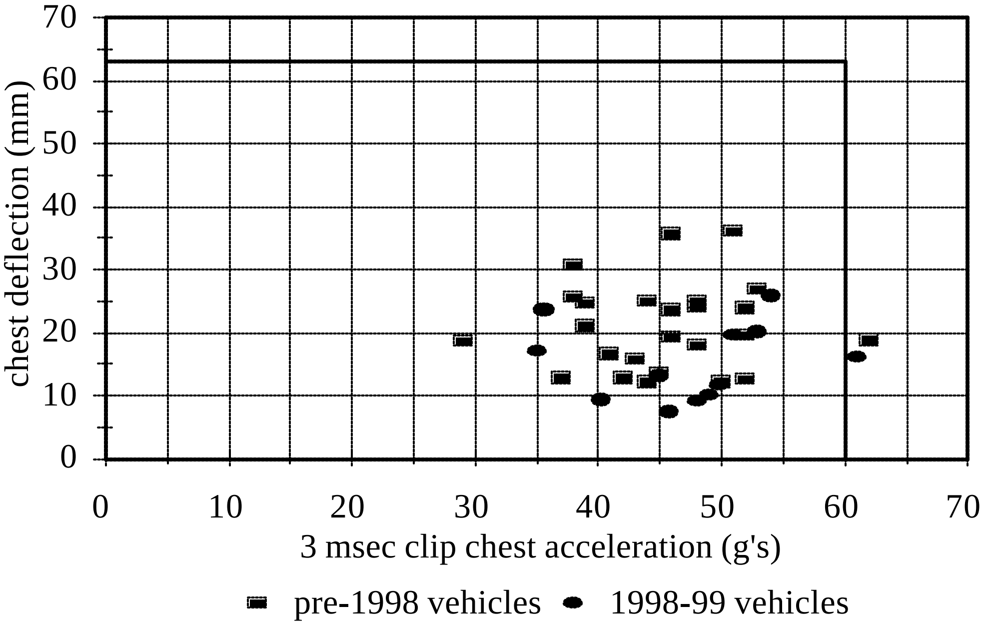

Figure D-4. **1996 to 1999 FMVSS 208 crash tests with the ATD in the driver position and performance limits for chest acceleration and deflection for the 50th percentile male dummy.** The passing rate for the dummy in the driver position is 93%.

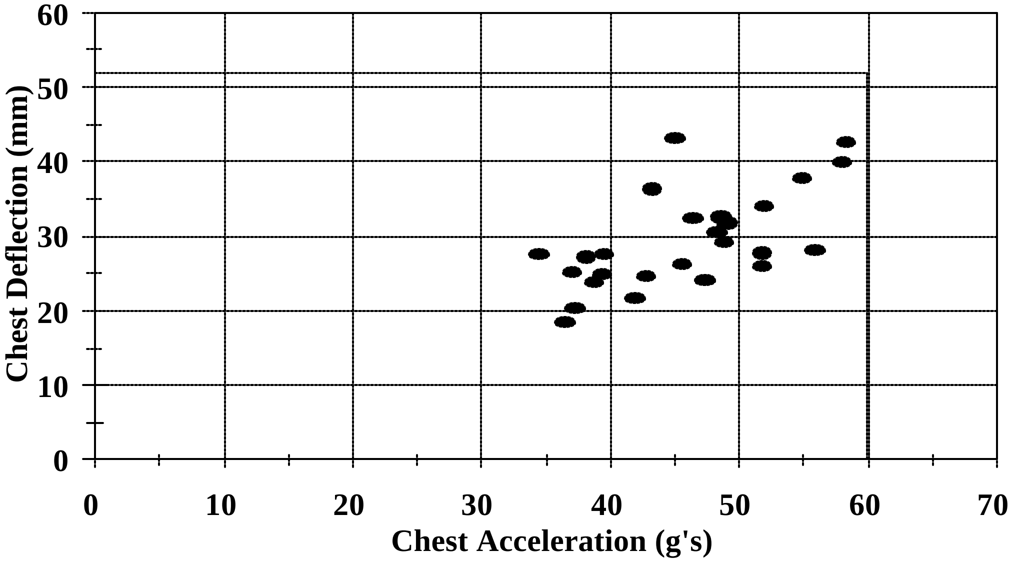

Figure D-5. **1998 - 1999 FMVSS 208 type crash tests with the belted 5th percentile female Hybrid III dummy in the driver position and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the driver position is 100%.

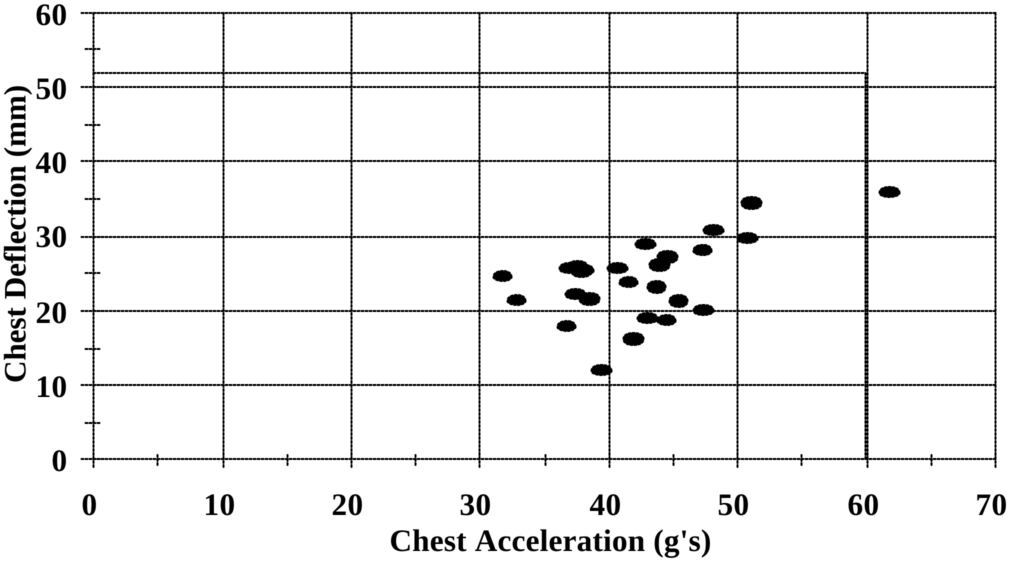

Figure D-6. **1998 - 1999 FMVSS 208 type crash tests with the belted 5th percentile female Hybrid III dummy in the passenger position and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the passenger position is 96%.

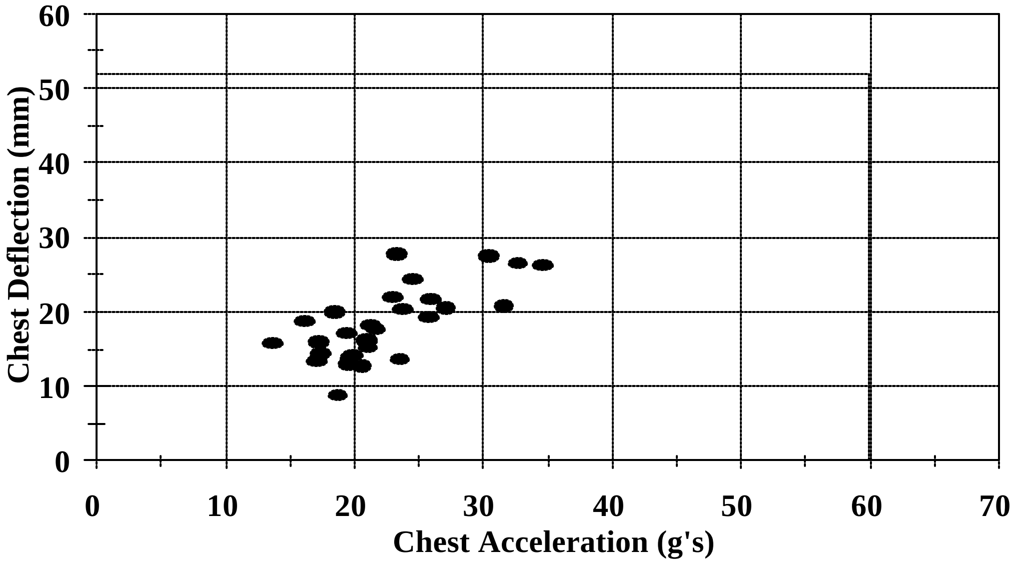

Figure D-7. **1998 - 1999 vehicle offset crash tests with the 5th percentile female dummy in the driver position and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the driver position is 100%.

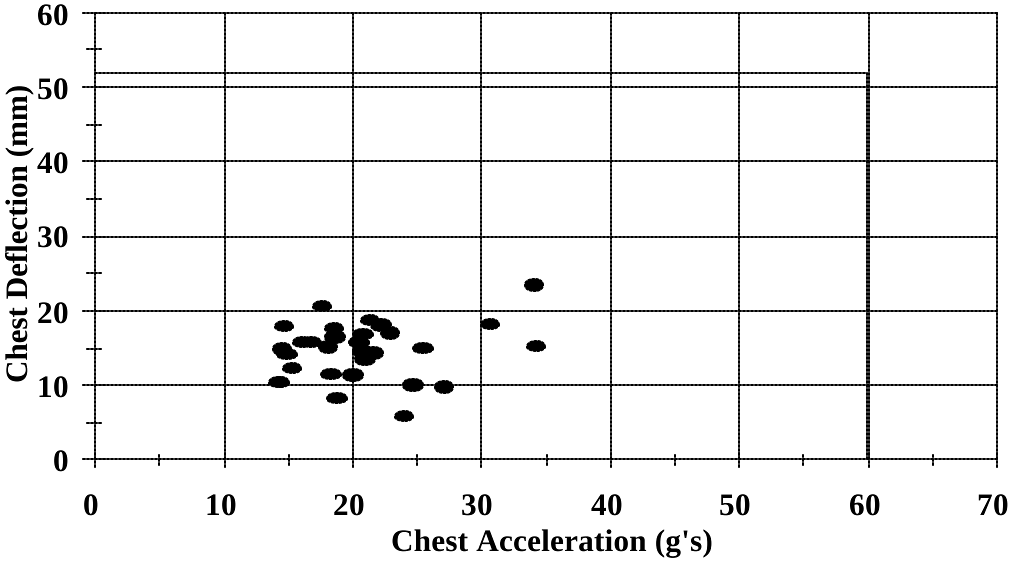

Figure D-8. **1998 - 1999 vehicle offset crash tests with the 5th percentile female dummy in the passenger position and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the passenger position is 100%.

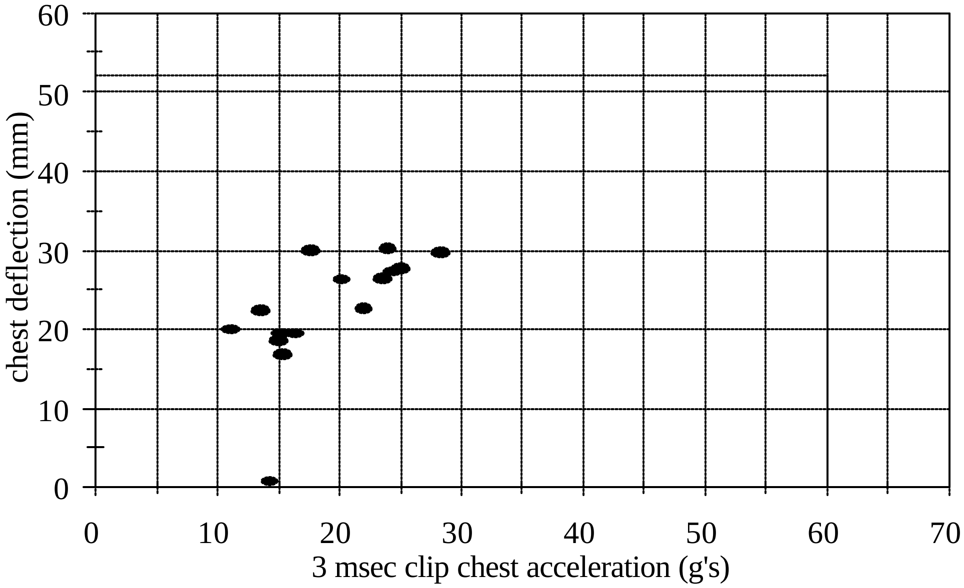

Figure D-9. **1996 - 1999 air bag systems with the 5th percentile female dummy in the OOP Position-1 Condition and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the OOP Position 1 condition is 100%.

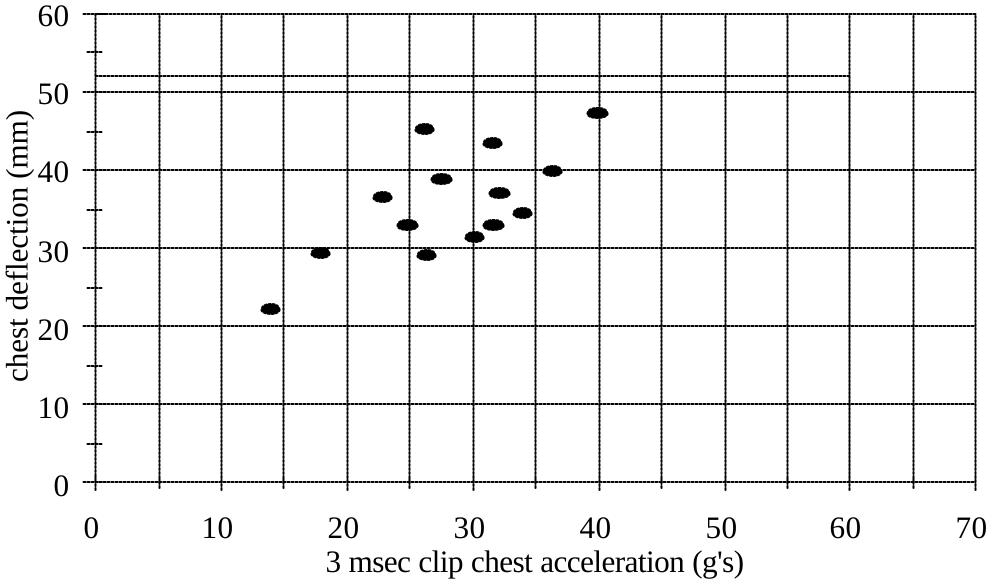

Figure D-10. **1996 - 1999 air bag systems with the 5th percentile female dummy in the OOP Position 2 Condition and the performance limits for chest acceleration and deflection for the 5th percentile female dummy.** The passing rate for the dummy in the OOP Position-2 condition is 100%.

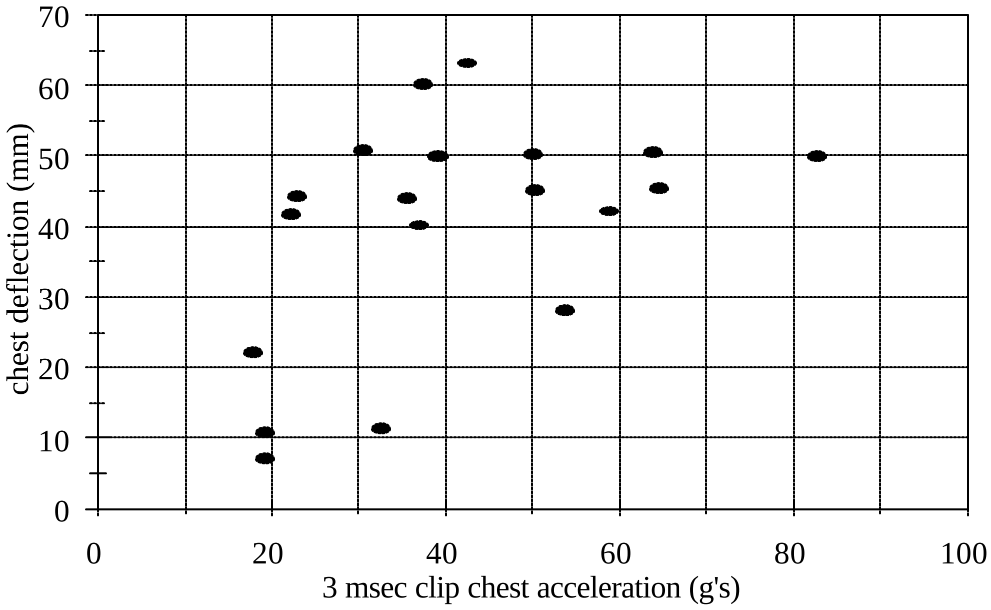

Figure D-11. 1996 -1999 air bag systems with the 6-year old Hybrid III dummy in the OOP Position 1 tests and the performance limits for chest acceleration and deflection for the 6 year-old dummy. The chest has zero clearance from the instrument panel. The passing rate for the dummy in this OOP condition is 26%.

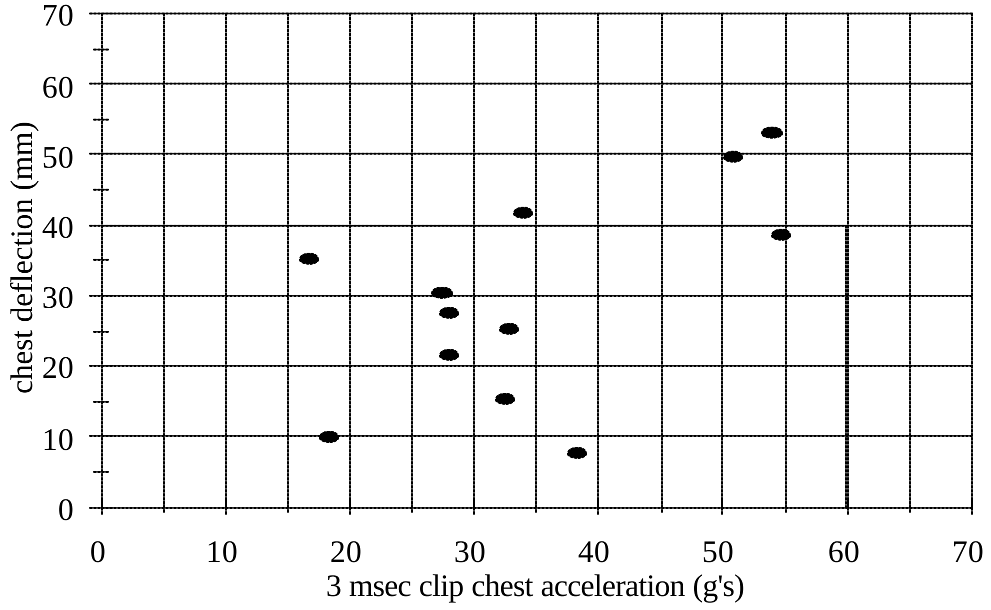

Figure D-12. 1996 -1998 air bag systems with the 6-year old Hybrid III dummy in the OOP Position 2 tests and the performance limits for chest acceleration and deflection for the 6 year-old dummy. The chest has a 4 inch clearance from the instrument panel. The passing rate for the dummy in this OOP condition is 75%.

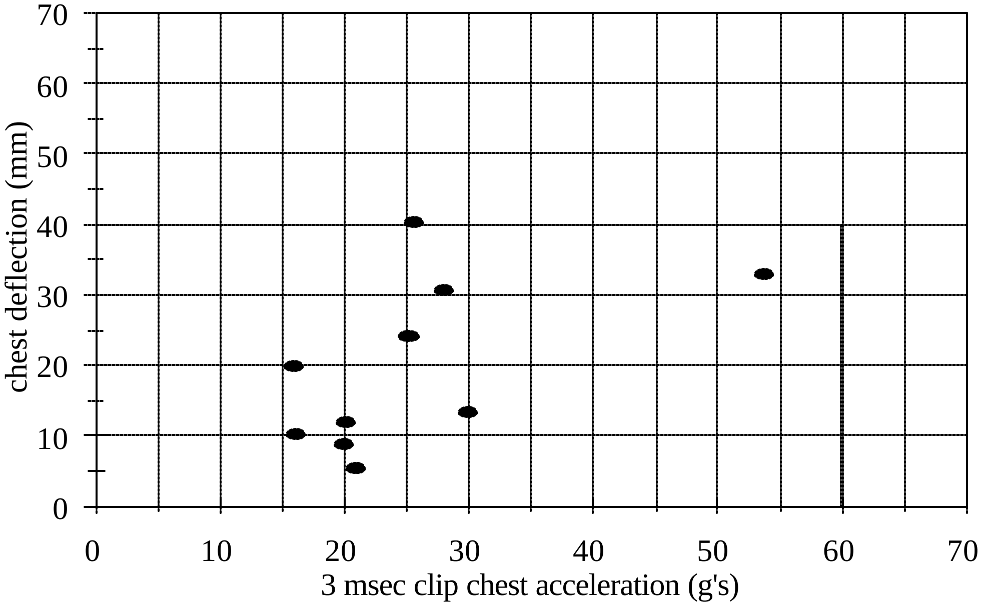

Figure D-13. 1996 -1998 air bag systems with the 6-year old Hybrid III dummy in the OOP position 1 tests and the performance limits for chest acceleration and deflection for the 6 year-old dummy. The chest has an eight inch clearance from the instrument panel. The passing rate for the dummy in this OOP condition is 90%.

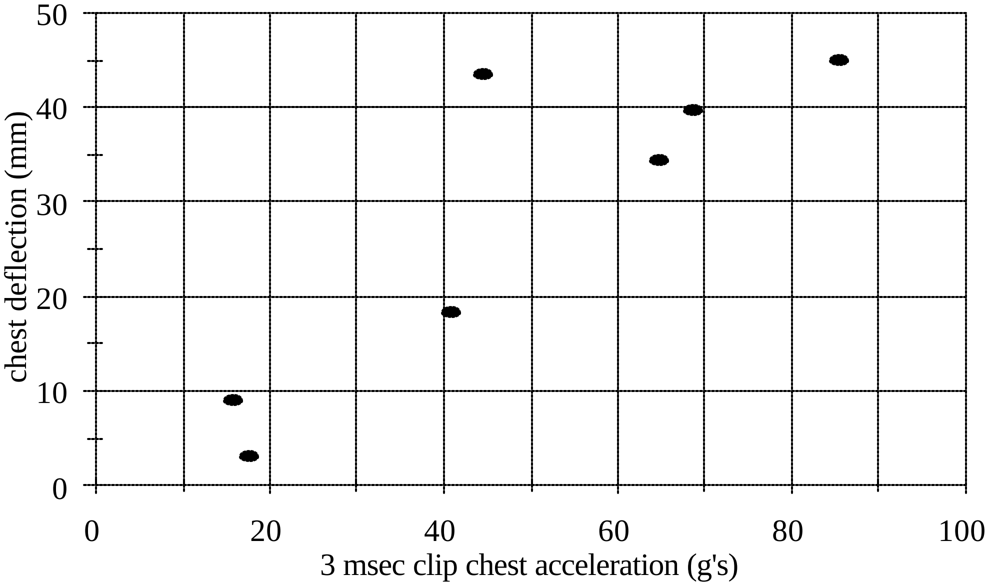

Figure D-14. 1999 air bag systems with the 6-year old Hybrid III dummy in the OOP Position 2 tests and the performance limits for chest acceleration and deflection for the 6 year-old dummy. The head has zero clearance from the instrument panel. The passing rate for the dummy in this OOP condition is 43%.

Appendix E

Statistical Analysis Procedures for Developing Injury Risk Curves from Biomechanical Test Data

Statistical Analysis Procedures for Developing Injury Risk Curves from Biomechanical Test Data

Introduction

In impact biomechanics tests, the injury outcome, which is in general nominal, is the dependent variable and the independent variables are the impact levels and other response variables. Specimen characteristics and test conditions are the confounders. For conditions where the specimen sustains an injury, the injury threshold of the specimen is lower than the applied risk factor level and vice versa. The objective of analysis procedures are to (1) identify a risk factor or a combination of risk factors which have the highest injury predictive ability among all other factors; (2) identify confounders and control for them; and (3) estimate the cumulative probability of injury curve of the population using the identified risk factors.

Analysis Procedures

Three popular methods of analysis of biomechanical test data are (1) Logistic Regression, (2) Mertz-Weber method, and (3) Certainty method. A brief description of each procedure is provided below:

> Logistic Regression: This procedure uses the maximum likelihood method to estimate the parameters of the assumed distribution so that the probability of getting the values of the dependent variable in the data sample is as high as possible. Regression methods are versatile, well established procedures where it is easy to handle different types of data simultaneously. This method provides good diagnostics on the goodness of fit and predictive ability of models. The method allows good control of confounders and interaction effects. The method requires the assumption of a distribution which may result in loss of statistical power.
>
> Mertz-Weber Method: The Mertz-Weber method assumes that the injury threshold levels are normally distributed. The injured specimen with the lowest applied risk factor is defined as the weakest specimen and the uninjured specimen with the highest applied risk factor is defined as the strongest specimen. The mean of the threshold level distribution is the average of the risk factor associated with the weakest and strongest specimens. The standard deviation of the distribution is estimated using a median rank table where the number of observations between the weakest and strongest specimen associated risk levels are taken into consideration. The Mertz-Weber method essentially uses only two observations from a data sample. Therefore, there is significant loss of statistical power. The method provides no diagnostics on goodness of fit or predictive ability of models. The method only works with one continuous variable at a time so it offers no control of confounding or interaction effects.
>
> Certainty Method: The Certainty Method is an empirical technique where data is categorized into two groups. At a prescribed level of the risk factor, injured data with associated risk factor below the prescribed level and uninjured data with associated risk factor above the prescribed

level are categorized in the “certainty group” . The rest of the data is categorized in the “uncertainty group”. The probability of injury at the prescribed threshold level is obtained using only the data in the certainty group. Since this method discards information in the uncertainty group, there is loss in statistical power. This method also offers no diagnostics on the goodness of fit and predictive ability of the model. It is difficult to control for confounding and interaction effects using this method.

Simulation Study:

A simulation was conducted to compare the performance of the three analysis procedures: logistic regression, Mertz-Weber method, and the certainty method. For these simulations, specimens were randomly selected from a population with a Gaussian failure threshold distribution ($\mu=65$ and $s=25$) as shown in Figure E-1. Each specimen was then subjected to a risk factor level (applied force) which was selected randomly from a uniform distribution ranging between 20 and 120, as shown in Figure E-2. If the applied force level for a specimen exceeded its failure threshold level, then that specimen was considered to have failed. If the applied force for a specimen did not exceed its failure threshold level, then that specimen was considered to have not failed. Left and right censored observations were obtained in this manner. Table E.1 presents one such data set where the applied force, the specimen failure threshold level, and the failure outcome (failure=1 and non-failure=0) are provided. In this data set, the failure data point with the lowest dose level is not the “weakest specimen” as noted in the Mertz/Weber method. Also, the non-failure data point with the highest dose level is not the “strongest specimen”.

Initially, samples with 100 observations were simulated. Figures E-3 to E-8 are the results of three such simulations. In each case, the probability of injury curve from logistic regression more closely reflects the actual failure threshold curve of the population than does the curve generated using the Mertz-Weber method and the certainty method. The Mertz-Weber and certainty methods always underestimate the variance in the data. Note that in simulation 4 (Figure E-4), the Mertz-Weber derived probability curve is significantly different from the actual probability of injury and the logistic regression and certainty method derived probability curve. Since the Mertz-Weber method uses only two data points, it is significantly influenced by outliers as in this data set, where there is a failure at a low applied force of 29.

Next, the effect of sample size on the estimate of the population failure threshold levels was examined by changing the size of the sample. The sample size was changed from 50 to 200 observations by adding or removing random observations from the sample from simulation 5. For a sample size of 50 observations, all three methods of analysis are not accurate (Figure E-6) though logistic regression still is the closest estimate of the population parameters at low applied force level. The logistic regression curve is a better estimate of the population threshold curve than the certainty and Mertz-Weber methods for a sample size of 100 observations (Figure E-7). For a sample size of 200 observations, the curve derived from logistic regression is almost identical to the population cumulative distribution of failure threshold (Figure E-8). There is not much change in the probability of injury curves derived from the Mertz-Weber and Certainty methods as the sample size is increased. Since the Mertz-Weber and Certainty methods do not employ all the observations in estimating the population parameters, there is not much effect of sample size on their parameter estimates.

The log-likelihood value (the log of the probability of getting the data in the sample) is an estimate of the goodness of fit of the data. This log-likelihood or LogL value is the highest for the logistic regression curve (Table E-2) for each of the simulations. This suggests that the logistic regression curve best represents the data in the sample. Note that the actual threshold curve has a lower likelihood value than the logistic regression curve. This is because the sample size is small and the distribution of injury threshold levels in the sample is not the same as that of the population.

Estimation of Failure Threshold Levels:

Consider the situation where an applied force level corresponding to a 20% probability of failure of the population is of interest. The applied force corresponding to a 20% probability of failure obtained from logistic regression and the Mertz-Weber method for each of the simulation is shown in Table E-3. The average dose level at 20% probability of failure for the first six simulations (100 observations) from the Mertz-Weber method is 52.48 and for the certainty method is 52.2. This is considerably higher than the dose level of 43.95 for a 20% probability of failure of the population in consideration. The dose level at 20% probability of failure from logistic regression for the first 6 simulations is 45.87 which is closer to that of the population than the Mertz-Weber method.

The average of the population probability of failure which corresponds to the dose level at 20% probability of failure from the Mertz-Weber and certainty methods is 31% as compared to 22.3% from logistic regression. This implies that the Mertz-Weber and certainty methods grossly underpredicts the probability of failure at lower dose levels and so threshold levels selected at low probability of failure using the Mertz-Weber method may not offer adequate protection.

Only six simulations were considered here. It is expected that as the number of simulations is increased, the average dose level at 20% probability of failure from logistic regression would be almost the same as that of the population. However, the corresponding dose level from the Mertz-Weber method will still be higher than that of the population.

When the sample size is increased to 200 observations (simulation 7), the dose level at 20% probability of failure from logistic regression is almost the same as that of the population while the Mertz-Weber method still has a higher corresponding dose level.

Table E.1: Data from Simulation 5

dose	actual threshold	failure outcome	
117.662	61.836	1	
38.385	85.666	0	
23.816	96.762	0	
41.878	11.237	1	Z weakest specimen
100.504	79.528	1	
43.168	101.644	0	
119.029	47.284	1	
105.454	57.293	1	
48.495	43.334	1	

51.547	62.907	0	
118.615	88.910	1	
119.070	66.904	1	
37.392	49.398	0	
37.529	68.925	0	
88.043	69.840	1	
113.657	56.224	1	
61.720	69.801	0	
51.463	74.760	0	
90.040	70.918	1	
107.490	83.041	1	
71.091	85.642	0	
60.352	79.601	0	
59.199	59.946	0	
61.864	39.564	1	
57.267	83.311	0	
100.067	44.686	1	
64.669	97.837	0	
74.527	84.110	0	
69.013	71.581	0	
103.141	47.896	1	
86.849	51.151	1	
38.870	99.016	0	
60.836	116.968	0	
105.344	121.826	0	Mertz defined strongest specimen
28.105	63.425	0	
64.678	77.452	0	
117.050	38.974	1	
25.761	110.173	0	
93.706	101.713	0	
35.692	76.699	0	
96.843	17.697	1	
111.121	90.813	1	
52.397	71.339	0	
102.822	49.575	1	
119.454	118.224	1	
96.582	59.973	1	
96.440	75.849	1	
58.997	38.696	1	
48.978	68.314	0	
69.296	54.083	1	
59.823	57.468	1	
102.777	76.403	1	
45.092	47.939	0	
87.985	97.208	0	
70.341	44.000	1	
115.085	103.438	1	
23.810	66.824	0	
95.661	32.636	1	
35.471	33.959	1	Mertz defined weakest specimen
33.781	87.519	0	

45.987	77.327	0	
63.021	75.814	0	
86.050	97.745	0	
49.383	49.846	0	
58.681	73.547	0	
59.710	53.660	1	
48.557	77.516	0	
107.655	82.580	1	
20.873	70.497	0	
98.853	79.540	1	
41.600	76.241	0	
76.213	105.321	0	
28.694	78.560	0	
87.152	49.821	1	
104.419	45.165	1	
117.950	68.108	1	
28.737	93.466	0	
113.396	24.117	1	
66.884	78.924	0	
112.471	43.332	1	
79.955	100.935	0	
97.764	56.058	1	
40.733	16.129	1	
47.371	33.388	1	
39.570	42.536	0	
71.309	74.224	0	
45.738	70.984	0	
28.553	95.541	0	
41.627	85.186	0	
92.658	124.640	0	Z strongest specimen
95.623	24.022	1	
105.921	57.262	1	
45.929	64.692	0	
113.825	53.071	1	
33.966	62.577	0	
28.637	69.669	0	
83.246	63.893	1	
70.058	57.108	1	
72.312	69.651	1	
29.696	110.722	0	

Table E.2: Log-likelihood values for the sample in each simulation.

Simulation No.	sample size n	actual threshold	Logistic	Mertz-weber	Certainty
simulation 1	100	-51.29	-50.51	-57.64	-59.73
simulation 2	100	-39.61	-39.37	-42.08	-41.75
simulation 3	100	-43.55	-43.26	-52.42	-48.41
simulation 4	100	-37.47	-36.06	-47.03	-36.97
simulation 5	100	-44.52	-43.08	-50.79	-46.35
simulation 6	100	-35.29	-34.05	-39.2	-37.12
simulation 5	50	-21.2	-19.83	-22.13	-21.21
simulation 5	75	-33.38	-31.87	-36.49	-34.08
simulation 5	150	-64.36	-64.37	-76.76	-69.61
simulation 5	200	-87.37	-87.96	-107.39	-97.04

Table E.3: Dose levels at 20 % probability of failure from Mertz-Weber method and logistic regression and the probability of failure of the population at the dose levels corresponding to 20% probability of failure from the Mertz-Weber method and logistic regression.

	Force at 20% Probability of Failure			Actual Probability of Injury from Forces in Columns 2, 3, and 4		
	Column 2 M-W	Column 3 Logistic	column 4 certainty	M-W	Logistic	Certainty
Simulation 1	57.83	41.61	55.8	0.387	0.175	0.36
Simulation 2	51.63	46.99	54.0	0.296	0.235	0.33
Simulation 3	52.96	38.12	46.3	0.315	0.141	0.23
Simulation 4	46.78	52.47	55.0	0.233	0.308	0.34
Simulation 5	57.87	50.93	54.5	0.388	0.287	0.34
Simulation 6	47.80	45.12	47.8	0.246	0.213	0.25
Average	**52.48**	**45.87**	**52.2**	**0.311**	**0.223**	**0.31**
Simulation 7	57.21	44.0	52.2	0.377	0.2	0.3

* The dose level at 20% probability of failure of the population under consideration (μ=65 and s =25) is 43.95.

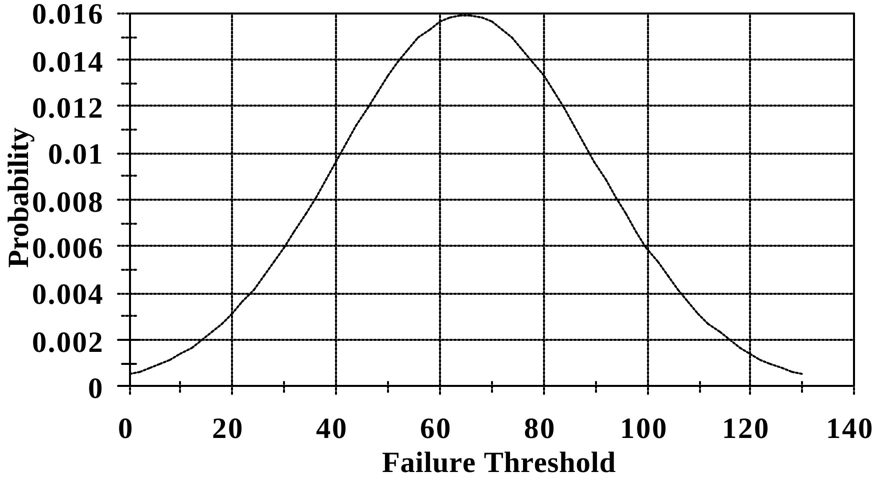

Figure E-1. Probability distribution of failure threshold levels in the population

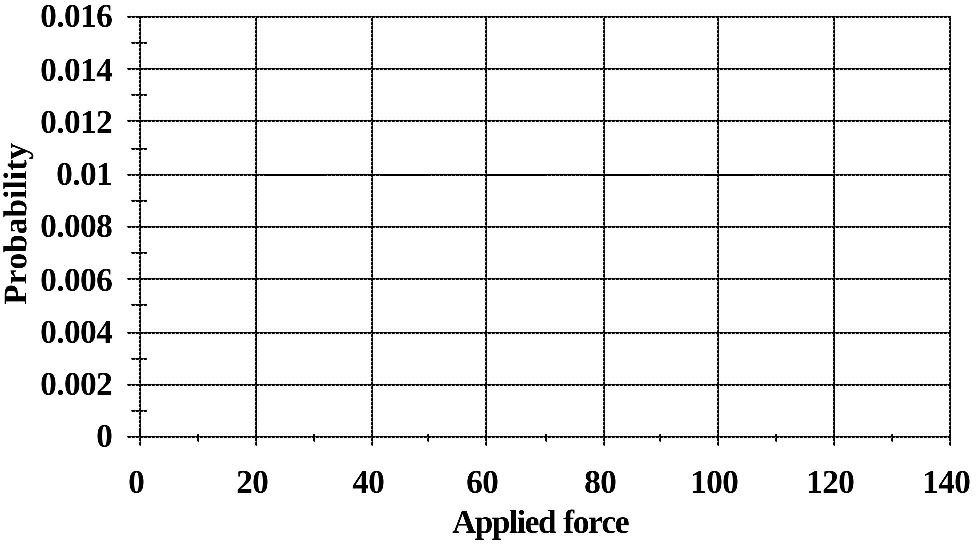

Figure E-2. Probability distribution of applied risk factor

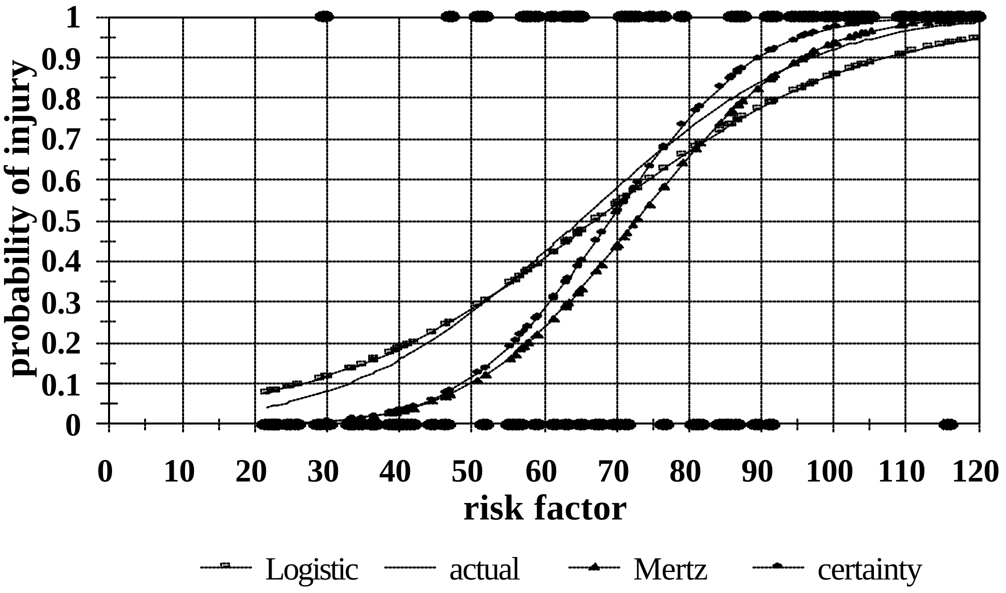

Figure E-3. Results of analysis of data set from simulation 1 with 100 observations.

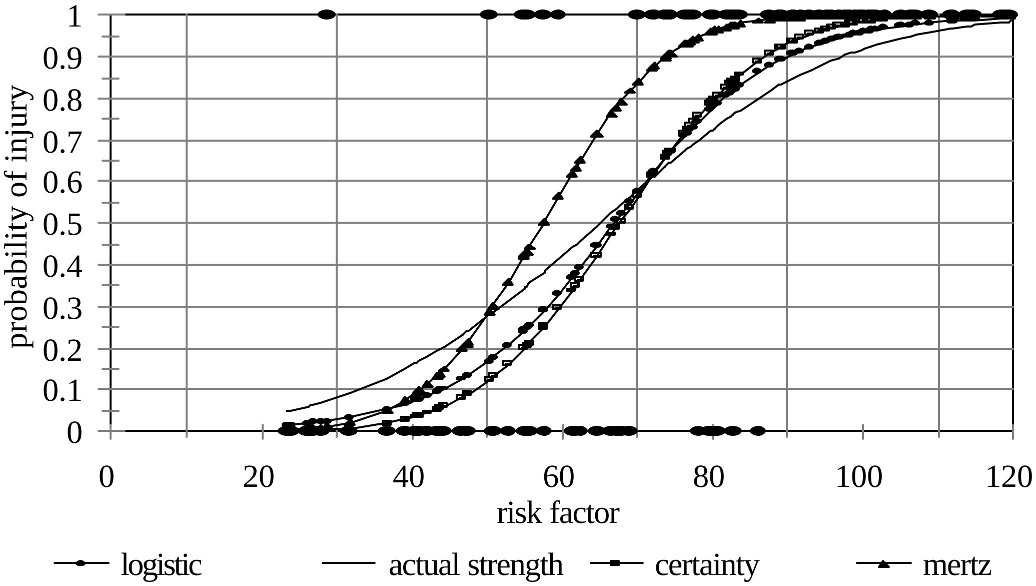

Figure E-4. Results of analysis of data set from simulation 4 with 100 observations.

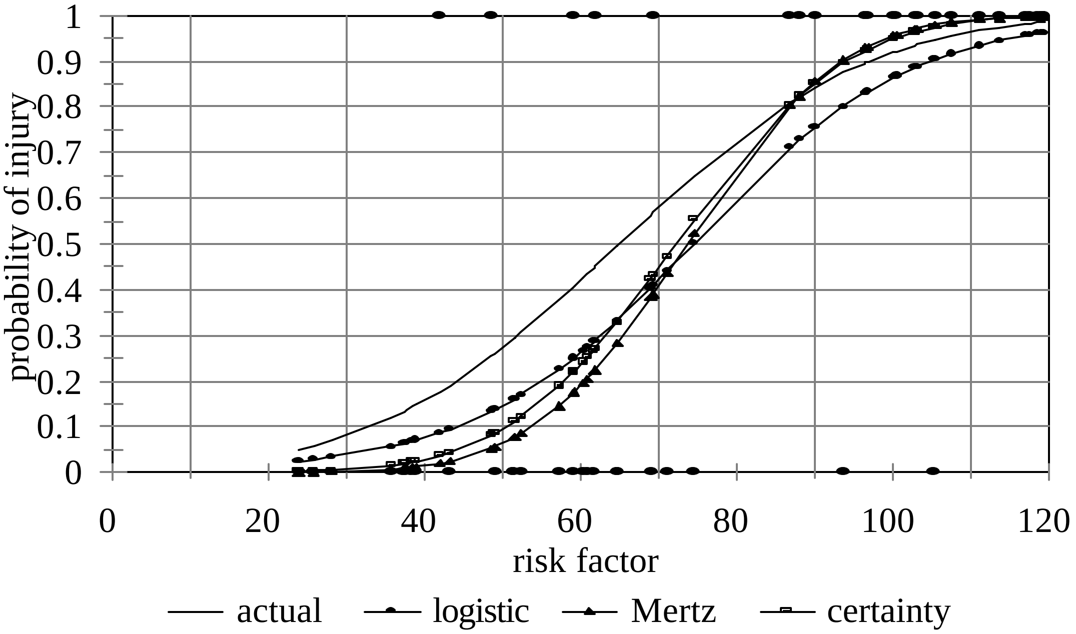

Figure E-5. Results of analysis of data set from simulation 5 with 50 observations.

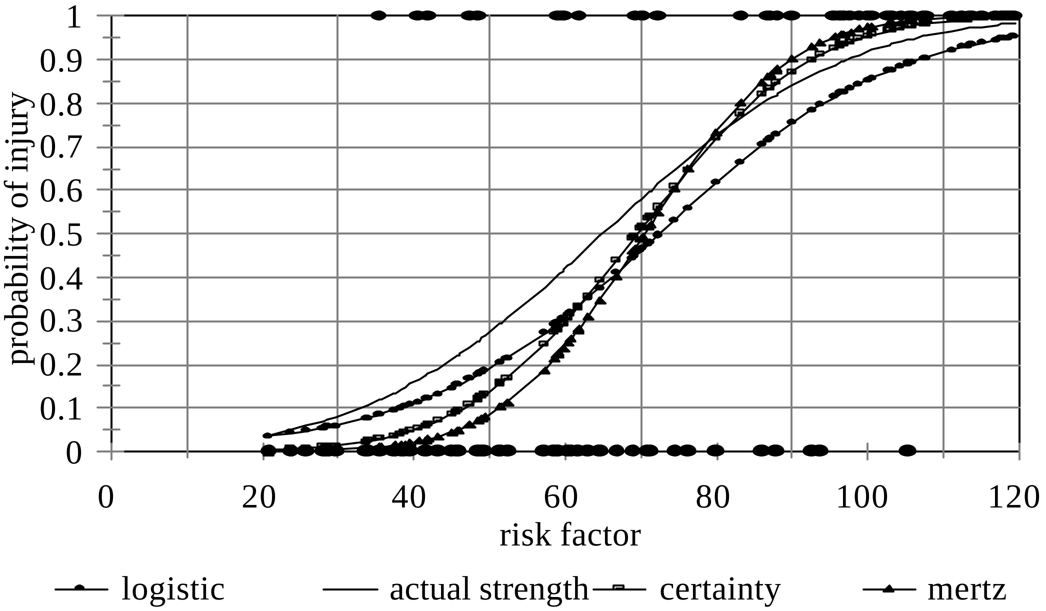

Figure E-6 . Results of analysis of data set from simulation 5 with 100 observations.

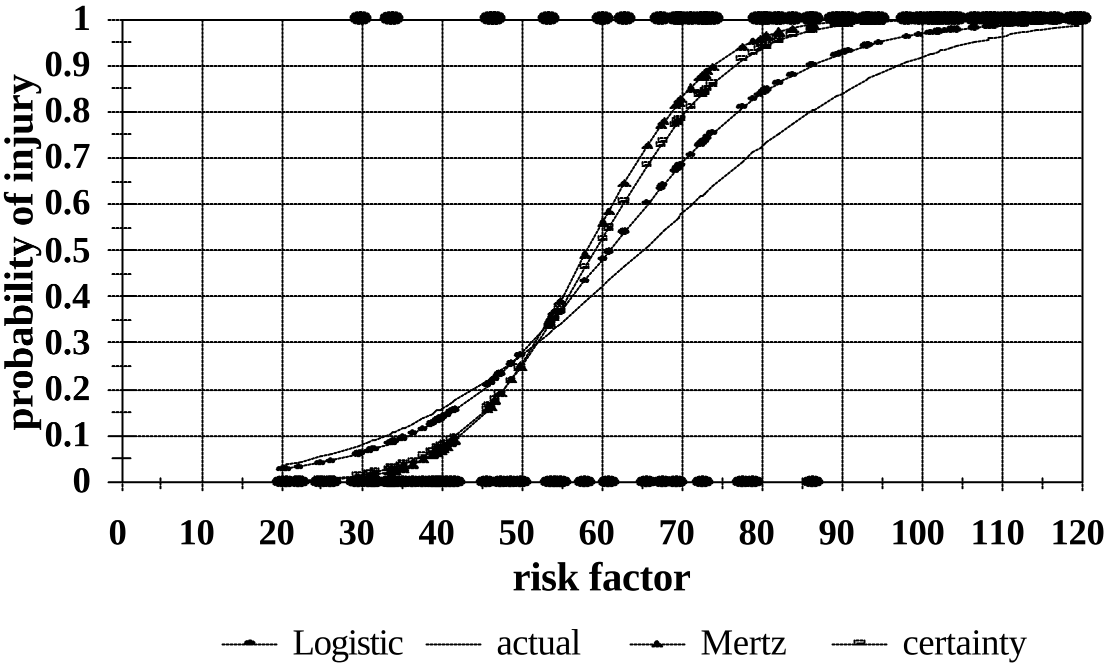

Figure E-7. Results of analysis of data set from simulation 6 with 100 observations.

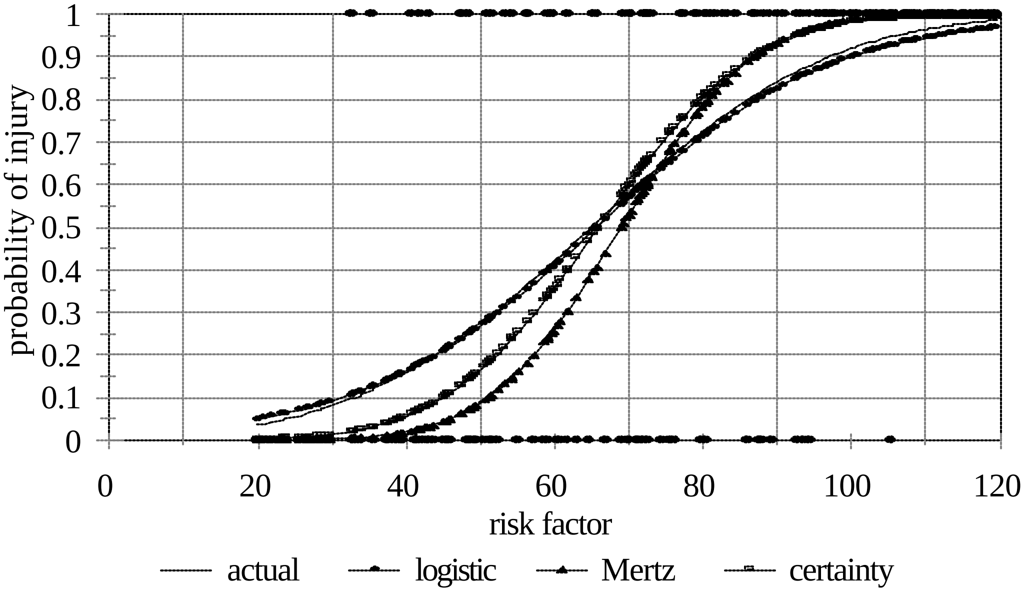

Figure E-8. Results of analysis of data set from simulation 5 with 200 observations.

Conclusion:

Results of the simulation study showed that

1. Logistic regression is more accurate in estimating the population threshold levels than the certainty method or the Mertz-Weber method.
2. The accuracy of the estimates using logistic regression increased with increase in sample size. Sample size did not have much effect on the other two methods of analysis.
3. Mertz-Weber and the Certainty methods result in a significant loss of power due to loss of information. Therefore, the population parameters were not estimated accurately even for large sample size.
4. The Mertz-Weber and the certainty methods underestimate the standard deviation of the population distribution. Therefore, at low levels of risk factor, these methods underestimate the probability of injury.
5. The estimated risk factor levels at low probability of injury (<40%) using the Mertz-Weber and the Certainty methods is always higher than the actual levels in the population. Therefore, these methods overestimate the population injury threshold levels.
6. Due to the improved accuracy of estimation of population parameters and the greater versatility of logistic regression to handle different types of variables, to control for confounding, to account for interaction between independent variable, and to provide better diagnostics, logistic regression is the choice of analysis of biomechanical impact test data.

Appendix F

Age-dependent Neck Scale Factors

Appendix F: Age-dependent Neck Scale Factors Based on Geometrical and Spine Component Data under Tension, Extension, Compression, and Flexion

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This document presents the method used to calculate the scale factors for the neck of one, three, and six year old children, and 5th percentile adult female and 50th percentile adult male under tension, extension, compression, and flexion. The variations in the mechanical properties of each spinal component (e.g., vertebra, discs, ligaments, cartilage, spinal cord, and muscles) were combined with the neck overall geometrical parameters [1-12]. Material property data were obtained from literature and in-house tests conducted at the MCW under each load vector. The active components of the spine were identified, and a statistically based relationship was established for each component that related its material property to age. The data were normalized with respect to the adult, and a mean value representing the material scale factor was obtained. This material scale factor was combined with the geometrical scale factors (Appendix F(a)). For example, at a specific age, under compression, material properties of the vertebra, disc, and cartilage were averaged to obtain a materially scaled factor using the adult male as standard. The overall neck cross-sectional area factor for this age was multiplied by the above-determined material factor to obtain the combined scaling factor. Similar procedures were adopted for tension, extension, and flexion. The derived scale factors using this combined spinal material and geometrical approach as a function of age and loading mode are given in Table F-1. The spinal component material property data for the 5th percentile adult female and 50th percentile adult male were considered standard because skeletal maturity is completely achieved for these adult groups.

Table F.1: Scale factors as a function of loading mode derived from combined spinal component material and geometrical analysis.

Age/Group	**Tension**	**Extension**	**Compression**	**Flexion**
1 year	0.26	0.22	0.26	0.23
3 years	0.29	0.32	0.28	0.33
6 years	0.35	0.41	0.34	0.42
5th female	0.63	0.70	0.63	0.70
50th male	1.00	1.00	1.00	1.00

References:

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APPENDIX F(a)

Scale Factors under Tension (l_T)

Table F(a).1: Material Effect of Active Spinal Component (λ_M)

	1 year	**3 years**	**6 years**	**5th female**	**50th male**
Vertebrae	0.79	0.77	0.77	1.0	1.0
Disc	0.68	0.7	0.73	1.0	1.0
Cartilage	0.79	0.81	0.84	1.0	1.0
Ligament - ALL (AAOM)	0.84	0.87	0.89	1.0	1.0
- PLL (TM)	0.84	0.87	0.89	1.0	1.0
- ISL	0.84	0.87	0.89	1.0	1.0
- CL	0.84	0.87	0.89	1.0	1.0
- LF (AOM)	0.76	0.78	0.81	1.0	1.0
Spinal cord	0.41	0.44	0.49	1.0	1.0
Neck muscles	0.54	0.58	0.63	1.0	1.0
Average	**0.733**	**0.756**	**0.783**	**1.0**	**1.0**

Table F(a).2 : Geometrical Effect of Overall neck cross-sectional area ratio (λ_G)

	l_G
1 year	0.35
3 years	0.39
6 years	0.45
5th female	0.63
50th male	1.0

Table F(a).3 : Combined Material and Geometry Effect ($\lambda_T = \lambda_M \times \lambda_G$)

	λ_T
1 year	0.26
3 years	0.29
6 years	0.35
5th female	0.63
50th male	1.0

Scale Factors under Extension (l_E)

Table F(a).4 : Material Effect of Active Spinal Component (λ_M)

	1 year	3 year	6 years	5th female	50th male
Vertebrae	0.79	0.77	0.77	1.0	1.0
Disc	0.68	0.70	0.73	1.0	1.0
Cartilage	0.79	0.81	0.84	1.0	1.0
Ligament - ALL	0.84	0.87	0.89	1.0	1.0
- PLL	0.84	0.87	0.89	1.0	1.0
Spinal cord	0.41	0.44	0.49	1.0	1.0
Neck muscles	0.54	0.58	0.63	1.0	1.0
Average	0.699	0.72	0.749	1.0	1.0

Table F(a).5: Geometrical Effect of Overall neck cross-sectional area and length ratio (λ_G)

	area	neck length	Average (λ_G)
1 year	0.35	0.29	0.32
3 years	0.39	0.50	0.45
6 years	0.45	0.66	0.56
5th female	0.63	0.76	0.63
50th male	1.0	1.0	1.0

Table F(a).6 : Combined Material and Geometry Effect ($\lambda_E = \lambda_M \times \lambda_G$)

	λ_E
1 year	0.22
3 years	0.32
6 years	0.41
5th female	0.7
50th male	1.0

Scale Factors under Compression (l_C)

Table F(a).7 : Material Effect of Active Spinal Component (λ_M)

	1 year	3 years	6 years	5th female	50th male
Vertebrae	0.79	0.77	0.77	1.0	1.0
Disc	0.68	0.70	0.73	1.0	1.0
Cartilage	0.67	0.70	0.74	1.0	1.0
Average	0.71	0.72	0.75	1.0	1.0

Table F(a).8 : Geometrical Effect of Overall neck cross-sectional area ratio (λ_G)

	λ_G
1 year	0.35
3 years	0.39
6 years	0.45
5th female	0.63
50th male	1.0

Table F(a).9 : Combined Material and Geometry Effect ($\lambda_C = \lambda_M$ x λ_G)

	λ_C
1 year	0.25
3 years	0.28
6 years	0.34
5th female	0.63
50th male	1.0

Scale Factors under Flexion (l_F)

Table F(a).10 : Material Effect of Active Spinal Component (λ_M)

	1 year	3 years	6 years	5th female	50th male
Vertebrae	0.79	0.77	0.77	1.0	1.0
Disc	0.68	0.7	0.73	1.0	1.0
Cartilage	0.79	0.81	0.84	1.0	1.0
Ligament - ISL	0.84	0.87	0.89	1.0	1.0
- CL	0.84	0.87	0.89	1.0	1.0
- LF	0.76	0.78	0.81	1.0	1.0
Spinal cord	0.41	0.44	0.49	1.0	1.0
Neck muscles	0.54	0.58	0.63	1.0	1.0
Average	0.706	0.728	0.756	1.0	1.0

Table F(a).11: Geometrical Effect of Overall neck cross-sectional area and length ratio (λ_G)

	Area	Length	Average (λ_G)
1 year	0.35	0.29	0.32
3 years	0.39	0.50	0.45
6 years	0.45	0.66	0.56
5th female	0.63	0.76	0.7
50th male	1.0	1.0	1.0

Table F(a).12 : Combined Material and Geometry Effect ($\lambda_F = \lambda_M \times \lambda_G$)

	λ_F
1 year	0.23
3 years	0.33
6 years	0.42
5th female	0.7
50th male	1.0

Appendix G

SNPRM Nij Program Listing

```
//          nij_v9.cpp
//---------------------------------------------------------------
//          SNPRM Nij (Version 9) Reference Implementation
//
//          This code is a reference implementation of the SNPRM Nij injury criteria
//                  this was written for purposes of clarity and no consideration has been made for speed. style,
//                  or efficiency.  The Standard C++ library was used to avoid any confusion due to c-style
//                  memory allocation.
//
//          Program Input:
//                  This program requires input of three ascii x-y files, where each line of the input
//                  file contains two floating point values, one for the time and one for the y value
//
//                  *** All three files must have the same number of points and the same time data ***
//                  *** All input data must be unfiltered and will be filtered within this program
//
//                  Additionally, the program queries for the dummy size and whether the condyle correction factor
//                  is to be applied
//
//          Program Output:
//                  The Nij injury criteria, the time of Peak injury
//---------------------------------------------------------------
#include <iostream>
#include <fstream>
#include <vector>
#include <ctype.h>

using namespace std;
typedef vector <double> DBLVECTOR;

#include "bwfilt.h"                                                     // bwfilt implementation

// declarations
bool ReadAsciiFile ( char *filename, DBLVECTOR &x, DBLVECTOR &y);
void VectorMax( float &Max, float &MaxTime, DBLVECTOR &time, DBLVECTOR &fVector);
void VectorMin( float &Min, float &MinTime, DBLVECTOR &time, DBLVECTOR &fVector);
double FindTimeStep( DBLVECTOR &time );

int main( int argv, char *argc[])
{
        DBLVECTOR tx, ty, tz, xForce, yMoment, zForce;
        char szbuf[255];

        // read in the filename for the x axis
        cout << "Enter file Name for X axis Force Data: "<< endl;
        cin >> szbuf;
        if ( !ReadAsciiFile(szbuf, tx, xForce) )
        {
                cout << "Error X axis data File" << endl;
                exit (0);
        }
```

```
// read in the filename for the y axis
cout << "Enter file Name for Y axis Moment Data: "<< endl;
cin >> szbuf;
if ( !ReadAsciiFile(szbuf, ty, yMoment) )
{
        cout << "Error Y axis data File" << endl;
        exit (0);
}

// read in the filename for the x axis
cout << "Enter file Name for Z axis Force Data: "<< endl;
cin >> szbuf;
if ( !ReadAsciiFile(szbuf, tz, zForce) )
{
        cout << "Error Z axis data File" << endl;
        exit (0);
}

// make sure all three files have identical time data
if ( (tx.size() != ty.size()) || (tx.size() != tz.size()) )
{
        cout << "Time data does not match between Axes" << endl;
        exit (0);
}
int i;
for (i=0; i<tx.size(); i++)
{
        if ( (tx[i]!=ty[i]) || (tx[i]!=tz[i]) )
        {
                cout << "Time data does not match between Axes" << endl;
                exit (0);
        }
}

// clear two of the time arrays - not needed any longer
ty.erase(ty.begin(), ty.end() );
tz.erase( tz.begin(), tz.end() );

// find the time step, and make sure that it is constant (within 1%)
double del = FindTimeStep( tx );
if (del<=0.0)
{
        cout << "Could not find a constant time step for the data" << endl;
        exit(0);
}

// Filter the data - assume unfiltered data
bwfilt( xForce, del, 600);
bwfilt( zForce, del, 1000);
bwfilt( yMoment, del, 600);
```

```
// Select the dummy type
int nDummyType=0;
cout << "1 - CRABI 12 month old Dummy" << endl;
cout << "2 - Hybrid III - 3 Year old Dummy" << endl;
cout << "3 - Hybrid III - 6 Year old Dummy" << endl;
cout << "4 - Hybrid III - 5th % female Dummy" << endl;
cout << "5 - Hybrid III - 50th % male Dummy" << endl;
cout << "6 - Hybrid III - 95th % male Dummy" << endl;
cout << endl << "Enter Dummy Type :";
cin >> nDummyType;
if ( (nDummyType <=0) || (nDummyType > 6) )
{
        exit( 0 );
}

// set the critical values based on the dummy type
double CVt, CVc, mCVf, mCVe, fCondyle;
switch (nDummyType)
{
case 1:                                         // CRABI 12 month old Dummy
        CVt = 1465.0;
        CVc = 1465.0;
        mCVf =  43.0;
        mCVe =  17.0;
        fCondyle = 0.0058;
        break;
case 2:                                         // Hybrid III - 3 Year old Dummy
        CVt = 2120.0;
        CVc = 2120.0;
        mCVf = 68.0;
        mCVe =  27.0;
        fCondyle = 0.0;
        break;
case 3:                                         // Hybrid III - 6 Year old Dummy
        CVt = 2800.0;
        CVc = 2800.0;
        mCVf = 93.0;
        mCVe =  39.0;
        fCondyle = 0.01778;
        break;
case 4:                                         // Hybrid III - 5th % female Dummy
        CVt = 3370.0;
        CVc = 3370.0;
        mCVf = 155.0;
        mCVe =  62.0;
        fCondyle = 0.01778;
        break;
case 5:                                         // Hybrid III - 50th % male Dummy
        CVt = 4500.0;
        CVc = 4500.0;
        mCVf = 310.0;
```

```
            mCVe = 125.0;
            fCondyle = 0.01778;
            break;
case 6:                                         // Hybrid III - 95th % male Dummy
            CVt = 5400.0;
            CVc = 5400.0;
            mCVf = 415.0;
            mCVe = 166.0;
            fCondyle = 0.01778;
            break;
}

// prompt for Condyle Correction
cout << "Correct for Occipital Condyle Offset (" << fCondyle << ") Y / N ?" << endl;
char yesNo;
cin >> yesNo;
yesNo = toupper( yesNo );

// compute the normalized data
DBLVECTOR Tension, Compression, Flexion, Extension;
for (i=0; i<tx.size(); i++)
{
            if (zForce[i] > 0 )
            {
                        Tension.push_back( zForce[i] / CVt );                    // Tension
                        Compression.push_back( 0.0f );
            }
            else
            {
                        Compression.push_back( -zForce[i] / CVc );   // Compression
                        Tension.push_back( 0.0f );
            }

            // Condyle Correction
            if (yesNo == 'Y')
            {
                        yMoment[i] -= xForce[i] * fCondyle;
            }

            if (yMoment[i] > 0 )
            {
                        Flexion.push_back( yMoment[i] / mCVf );                  // Flexion
                        Extension.push_back( 0.0f );
            }
            else
            {
                        Extension.push_back( -yMoment[i] / mCVe );               // Extension
                        Flexion.push_back( 0.0f );
            }
}
```

```
// find the maximums and the time of the maximum
float maxTension, maxCompression, maxShear, minShear;
float maxFlexion, maxExtension;
float tTension, tCompression, tShearmax, tShearmin;
float tFlexion, tExtension;
VectorMax( maxTension, tTension, tx, Tension);
VectorMax( maxCompression, tCompression, tx, Compression);
VectorMax( maxShear, tShearmax, tx, xForce);
VectorMin( minShear, tShearmin, tx, xForce);
VectorMax( maxFlexion, tFlexion, tx, Flexion);
VectorMax( maxExtension, tExtension, tx, Extension);

// Output the Maximums
cout << "Maximum Shear      \t" << maxShear << "\tat " << tShearmax << " ms" << endl;
cout << "Minimum Shear      \t" << minShear << "\tat " << tShearmin << " ms" << endl;
cout << "Maximum Tension    \t" << maxTension*CVt << "\tat " << tTension << " ms" << endl;
cout << "Maximum Compression\t"<<maxCompression*CVc <<"\tat "<<tCompression<<" ms" << endl;
cout << "Maximum Flexion    \t" << maxFlexion*mCVf << "\tat " << tFlexion << " ms" << endl;
cout << "Maximum Extension  \t" << maxExtension*mCVe<< "\tat " << tExtension << " ms" << endl;
cout << endl;

// Compute the Nij Values
DBLVECTOR Ntf, Nte, Ncf, Nce;
for (i=0; i<tx.size(); i++)
{
        if ( (Tension[i] > 0.0) && (Flexion[i]>0.0) )
                Ntf.push_back( Tension[i] + Flexion[i] );
        else
                Ntf.push_back( 0.0 );

        if ( (Tension[i] > 0.0) && (Extension[i]>0.0) )
                Nte.push_back( Tension[i] + Extension[i] );
        else
                Nte.push_back( 0.0 );

        if ( (Compression[i] > 0.0) && (Flexion[i]>0.0) )
                Ncf.push_back( Compression[i] + Flexion[i] );
        else
                Ncf.push_back( 0.0 );

        if ( (Compression[i] > 0.0) && (Extension[i]>0.0) )
                Nce.push_back( Compression[i] + Extension[i] );
        else
                Nce.push_back( 0.0 );
}

// save the Max Value and the Time of the Max Value
float maxNtf, maxNte, maxNcf, maxNce;
float tNtf, tNte, tNcf, tNce;
VectorMax( maxNtf, tNtf, tx, Ntf );
VectorMax( maxNte, tNte, tx, Nte );
```

```
    VectorMax( maxNcf, tNcf, tx, Ncf );
    VectorMax( maxNce, tNce, tx, Nce );

    // Output the results
    cout << "Maximum Ntf\t" << maxNtf << "\tat " << tNtf << " ms" << endl;
    cout << "Maximum Nte\t" << maxNte << "\tat " << tNte << " ms" << endl;
    cout << "Maximum Ncf\t" << maxNcf << "\tat " << tNcf << " ms" << endl;
    cout << "Maximum Nce\t" << maxNce << "\tat " << tNce << " ms" << endl;
    cout << endl;

    return 0;
}

bool ReadAsciiFile ( char *szFilename, DBLVECTOR &x, DBLVECTOR &y)
{
    ifstream inFile;

    inFile.open( szFilename );
    if (inFile.fail() )
    {
        return false;
    }

    double xTemp, yTemp;
    while ( !inFile.eof() )
    {
        inFile >> xTemp >> yTemp;
        // check for errors
        if (inFile.fail() )
        {
            // input failed - save the data we already have and return;
            if (x.size() > 0)
                break;
            // no data was read - return an error
            return false;
        }
        x.push_back( xTemp );
        y.push_back( yTemp );
    }
    // close the file
    inFile.close();
    return true;
}

void VectorMax( float &Max, float &timeMax, DBLVECTOR &time, DBLVECTOR &fVector)
{
    Max = timeMax = 0.0f;
    for (int i=0; i<fVector.size(); i++)
    {
        if (fVector[i] > Max)
        {
```

```
				Max = fVector[i];
				timeMax = time[i]*1000.0f;
			}
		}
}

void VectorMin( float &Min, float &timeMin, DBLVECTOR &time, DBLVECTOR &fVector)
{
		Min = timeMin = 0.0f;
		for (int i=0; i<fVector.size(); i++)
		{
			if (fVector[i] < Min)
			{
				Min = fVector[i];
				timeMin = time[i]*1000.0f;
			}
		}
}

double FindTimeStep( DBLVECTOR &time )
{
		// make sure there is data
		if ( time.size()<=2)
			return 0.0;

		double del = time[1]-time[0];
		double test;
		double tError = 0.01*del;				// allow a 1% deviation in time step
		for (int i=2; i<time.size(); ++i)
		{
			test = time[i] - time[i-1];
			if ( test<=0)
				// check for errors - time must be monotonically increasing
				return 0.0;
			else if ( abs(test-del) > tError)
				return 0.0;
		}
		return del;
}
```

```
// bwfilt.cpp

#include <math.h>
#include <vector>
#include <iostream>
typedef std::vector <double> DBLVECTOR;

template< class T >
inline
T const &
min( T const & x, T const & y ) { return ( ( x < y ) ? x : y ); }

//==============================================================================
//        In-Place Second-Order Butterworth Filter of Time Series
//
//        Function:
//                Filters data forward and backward with a second order
//                Butterworth algorithm, giving zero phase shift and according to the
//                SAE J211.  This algorthim operates on the -3db cutoff frequency, which is
//                indicated as Fn in the J211 s[ecification.  There is an overloaded entry
//                point which allows specifying one of the J211 Channel Frequency Classes.
//                This routine implements  the algorithm outlined in J211 and uses a reversed
//    mirror pre-start treatment for both the forward and reverse passes.
//
//        Authors: Stuart G. Mentzer, Stephen Summers
//
//        Fortran version - 5/95, C version 9/96, C++ standard library version 3/98
//
//        input:
//                y - pointer to data array (float)
//                del - time increment between points in y (float)
//                fCut - Cutoff Frequency, -3db, indicated as Fn in SAE J211
//        return:
//                0 on success
//                1 on failure
//==============================================================================

int bwfilt( DBLVECTOR &y, float del, float fCut)
{
  int nTailPoints, nHalfTailPoints, i;
  double f6db, wd, wa, a0, a1, a2;
  double b1, b2, x0, x1, x2, y0, y1, y2, ynfp2;

  int nPoints = y.size();
  // Check for a positive number of points
  if (nPoints <= 0 )
  {
          std::cout << " BWFILT Error - Nonpositive number of Data Points";
          return(0);
  }
```

```
// Check positive time step
 if (del <= 0 )
 {
         std::cout << " BWFILT Error - Nonpositive time step";
   return(0);
 }
 // Check positive cutoff frequency
 if (fCut <= 0 )
 {
         std::cout << " BWFILT Error - Nonpositive Cutoff Frequency";
   return(0);
 }
 if ( fCut > (0.5f/del*0.775) )
 {
         // sampling rate is lower than the cutoff frequency - return true
         //       BwFilt goes unstable as fCut approaches 0.5/del
         return 1;
 }

 // Set 6dB attenuation frequency
 f6db = fCut * 1.2465;

 // Compute filter coefficients per J211
 wd = 6.2831853L * f6db;
 wa = sin(wd * del * 0.5) / cos(wd * del * 0.5);
 a0 = wa*wa / (1. + sqrt(2.0)*wa + wa*wa);
 a1 = 2 * a0;
 a2 = a0;
 b1 = -2.0*(wa*wa - 1.0) / (1.0 + sqrt(2.0)*wa + wa*wa);
 b2 = (-1.0 + sqrt(2.0)*wa - wa*wa) / (1.0 + sqrt(2.0)*wa + wa*wa);

 // Set the number of tail points to use
 nTailPoints = (int)(0.01 / ( min(fCut*0.01, 1.0) * del) + 0.5);

 //SAE J211 reccomends at least 10 ms, increase if necessary
 i = (int) (0.01 / del + 0.5);
 if (nTailPoints < i)
         nTailPoints = i;

 // regardless of time step and Frequency spec, use at least one point
 if (nTailPoints < 1)
  nTailPoints = 1;

 // Make sure that enough data points exist for the tail, else cut back tail
 if (nTailPoints > nPoints)
 {
         //cout << "BWFILT tail length < 10 ms, does not satisfy SAE J211 reccomendation";
         nTailPoints = nPoints;
 }
```

```
// Set up pre-start array - Inverted mirror
 ynfp2 = 2 * y[0];
 x1 = ynfp2 - y[nTailPoints];
 x0 = ynfp2 - y[nTailPoints-1];
 y1 = 0.0;
 nHalfTailPoints = ( nTailPoints / 2 ) + 1;
 for (i=nHalfTailPoints; i<=nTailPoints; i++)
 {
   y1 = y1 + y[i];
 }
 y1 = ynfp2 - ( y1 / ( nTailPoints - nHalfTailPoints + 1 ) );
 y0 = y1;
 for (i=-nTailPoints+2; i<=-1; i++)
 {
   x2 = x1;
   x1 = x0;
   x0 = ynfp2 - y[-i];
   y2 = y1;
   y1 = y0;
   y0 = a0*x0 + a1*x1 + a2*x2 + b1*y1 + b2*y2;
 }

 // Filter forward
 for (i=0; i<nPoints; i++)
 {
   x2 = x1;
   x1 = x0;
   x0 = y[i];
   y2 = y1;
   y1 = y0;
   y0 = a0*x0 + a1*x1 + a2*x2 + b1*y1 + b2*y2;
   y[i] = (float) y0;
 }

 // setup the pre-start array for the backward filter
 ynfp2 = 2 * y[nPoints-1];
 x1 = ynfp2 - y[nPoints -1 -nTailPoints];
 x0 = ynfp2 - y[nPoints -2 -nTailPoints];
 y1 = 0.0;
 for (i=nHalfTailPoints; i<=nTailPoints; i++)
 {
   y1 = y1 + y[nPoints -1 -i];
 }
 y1 = ynfp2 - ( y1 / ( nTailPoints - nHalfTailPoints + 1 ) );
 y0 = y1;
 for (i=nPoints-nTailPoints+3; i<=nPoints-2; i++)
 {
   x2 = x1;
   x1 = x0;
   x0 = ynfp2 - y[i];
   y2 = y1;
```

```
    y1 = y0;
    y0 = a0*x0 + a1*x1 + a2*x2 + b1*y1 + b2*y2;
  }

  // Filter backwards
  for (i=nPoints-1; i>=0; i--)
  {
    x2 = x1;
    x1 = x0;
    x0 = y[i];
    y2 = y1;
    y1 = y0;
    y0 = a0*x0 + a1*x1 + a2*x2 + b1*y1 + b2*y2;
    y[i] = (float) y0;
  }

  return(1);
}

//
//    optional entry routine to BWFILT using a channel frequency class.
//    This routines translates the J211 Channel Frequency Class into
//    specified cutoff frequency (Fn).
//
int bwfilt( DBLVECTOR &y, float del, int nClass)
{
        if ( (nClass!= 60) && (nClass!=180) && (nClass!=600) && (nClass!=1000) )
                std::cout << "Frequency Channel Class is not specified in SAE J211";

        return(bwfilt( y, del, (float)(nClass*1.666667) ));
}

//
//      overloaded function definition to allow calling with separate array
//      pointers so that the original displacement data is not overwritten
//
int bwfilt( DBLVECTOR &y, DBLVECTOR &yf, float del, float fCut)
{
        for (int i=0; i<y.size(); i++)
                yf[i] = y[i];

        return(bwfilt( yf, del, fCut ));
}
```

```
// bwfilt.h
// butterworth filtering function prototypes
//
int bwfilt( DBLVECTOR &y, float del, float fCut);          // cutoff frequency
int bwfilt( DBLVECTOR &y, float del, int nClass);          // channel class
int bwfilt( DBLVECTOR &y, DBLVECTOR &yf, float del, float fCut);       // no overwrite
```