DAIMLERCHRYSLER

DaimlerChrysler Corporation
Matthew C. Reynolds
Director
Vehicle Compliance & Safety Affairs

June 26, 2000

The Honorable Rosalyn G. Millman
Deputy Administrator
National Highway Traffic Safety Administration
400 Seventh St. S.W.
Washington D.C. 20590

Re: NHTSA Docket No. 00-7013; Notice 1
Final rule; Interim Final Rule
FMVSS 208, Occupant Crash Protection
Petition for Reconsideration

Dear Ms. Millman:

DaimlerChrysler is submitting this Petition for Reconsideration to comment on some unresolved issues in the FMVSS 208 final rule/interim final rule. In general, DaimlerChrysler commends the Agency for its work on this rule. DaimlerChrysler has a strong and long-standing commitment to increasing vehicle safety through improvements in air bag technology. We support the final rule/interim final rule because it represents a carefully balanced approach to increasing occupant protection while minimizing the risks to children and others from air bag deployments.

DaimlerChrysler appreciates the Agency's consideration of the detailed comments we previously submitted. However, we believe further expansion on some of those comments may aid the Agency in a reconsideration of certain conclusions reached in this complex and difficult rulemaking. Some provisions of the final rule/interim final rule, if allowed to stand, will inhibit certain types of technology and may jeopardize low risk deployment strategies. We believe some modifications will allow greater flexibility to manufacturers without any degradation in safety.

Accordingly, DaimlerChrysler is submitting this Petition for Reconsideration for the following issues:

- Test speed separation between tests to determine the air bag stage to deploy in static low risk deployment tests and the lowest speed at which unbelted rigid barrier tests are conducted.
- The test conditions under which the air bag stage determination tests for low risk deployment are conducted.
- Adoption of the N_{ij} injury criteria without sufficient biomechanical basis for its relationship to injury mechanisms.

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DaimlerChrysler has also identified other technical issues with the final text of the regulation. To resolve these, DaimlerChrysler petitions the Agency to reconsider specific provisions of the final rule. These petitions for reconsideration, along with supporting documentation for each, are provided in the attached document. We have also participated in the development of the petition for reconsideration by the Alliance of Automobile Manufacturers (the Alliance), and support those comments in addition to our own. We have incorporated some complementary comments to those of the Alliance in part of the attached petition.

Finally, we also wish to comment on two requirements incorporated into this final rule: the adoption of a 40 km/h (25 mph) offset deformable barrier test and the use of a list of child restraints to demonstrate the compliance of suppression systems.

First, DaimlerChrysler remains concerned that the Agency adopted a 40 km/h (25 mph) offset deformable barrier test as a "sensor test" in this regulation. Although the Agency agreed that the concerns identified by DaimlerChrysler and other commenters had merit, it dismissed their applicability to a "low speed" deformable barrier test. Once again, DaimlerChrysler respectfully disagrees with this conclusion for the reasons set forth in the technical paper submitted with our December 1999 comments to the SNPRM (Docket No. NHTSA-99-6407-44). We would welcome the opportunity to discuss this issue further.

DaimlerChrysler is also concerned about the long-term practicability of using commercial child restraints for confirming compliance of air bag suppression systems. We continue to believe that it is necessary to address simultaneously the design of child restraints and vehicles in order to have highly reliable systems. We plan to work with other vehicle manufacturers through the Alliance of Automobile Manufacturers, and with additional interested parties to develop a suitable set of test fixtures for testing suppression systems.

We thank the Agency for considering this Petition for Reconsideration and the comments provided. Should you need additional information, or clarification of what is provided, please contact Mr. W. R. Edwards of my staff at (248) 576-7303.

Sincerely,

Matthew C. Reynolds
Director, Vehicle Compliance & Safety Affairs

cc: L. Robert Shelton, III
Stephen R. Kratzke
Clarke Harper (10 copies)
Docket Management (electronic filing)

/Attachment

DaimlerChrysler has carefully reviewed the final rule/interim final rule published in Docket number NHTSA-00-7013; Notice 1. After consideration of these revisions to the regulation, we are submitting the following petitions for reconsideration.

Low Risk Deployment

The low risk deployment options for small stature drivers and child passengers, as described in the final rule, have increased practicability as compared to the earlier proposals in either the NPRM or the SNPRM. Two issues, however, should be addressed further in order to provide the full benefit of this option to vehicle occupants and improve its viability to manufacturers. First, an increase in the separation of test speeds between the air bag stage determination test -- the "threshold test" -- (currently at 26 km/h or 16 mph) and the lowest speed for the unbelted rigid barrier tests (currently at 32 km/h or 20 mph) is needed to allow manufacturers increased flexibility in implementing this option. Second, we recommend that the test configuration of the threshold test should be changed to use the same sized test dummies that will be used in the static out-of-position (OOP) tests.

1. Separation of Test Speeds

DaimlerChrysler recommends an increase in the separation in speeds between the speed of the test used to determine what air bag stage to deploy in static low risk deployment tests and the lower bound of the high-speed, unbelted tests. The allowance of a 6 km/h (4 mph) separation in the final rule has the unintended effect of preventing a manufacturer from applying a low-power/low risk deployment inflator stage in all their air bag systems. The final rule calls for protecting an unbelted 50^{th} percentile male occupant during a rigid barrier test at speeds as low as 32 km/h (20 mph). There is a simultaneous requirement for static out-of-position tests to be conducted with whichever air bag stage is deployed during a 26 km/h (16 mph) rigid barrier test. While we appreciate the Agency's changes in the final rule from the SNPRM, we still believe these two requirements are in conflict and are inconsistent with the reality of crash sensing and air bag inflator technology.

The preamble of the final rule (Section VI.D.2., 65 FR 30706) suggests that the separation of test speeds will enable manufacturers to develop low risk deployment air bags systems:

> "Today's requirement builds in a 6 km/h (4 mph) "grey zone" that will allow manufacturers to deploy both inflator stages, if needed, in all high-speed tests, while preserving their ability to deploy only the first stage (or allow for deployment of a combination of benign stages) of the air bag in the low risk deployment tests."

DaimlerChrysler's response to the SNPRM (Docket No. NHTSA-99-6407-44) and our supplemental submission, "Need for Separation in Test Speeds for Low Risk Deployment Air Bag Stage Tests and High-Speed Rigid Barrier Tests" (Docket No. NHTSA-00-7013-13), provided both theoretical studies and actual developmental vehicle data that challenge the conclusion that a 6 km/h (4 mph) separation in speeds is adequate. We believe the Agency may have misinterpreted or underestimated the significance of our analyses. Both documents point out the relationship between the test speed grey zones (shown as typically about 10 km/h (6 mph) for the first stage and wider for the second stage) and time to fire. The need for rapid deployment decisions in order to limit the potential harm to out-of-position occupants widens the grey zone -- especially in the case of second stage deployments.

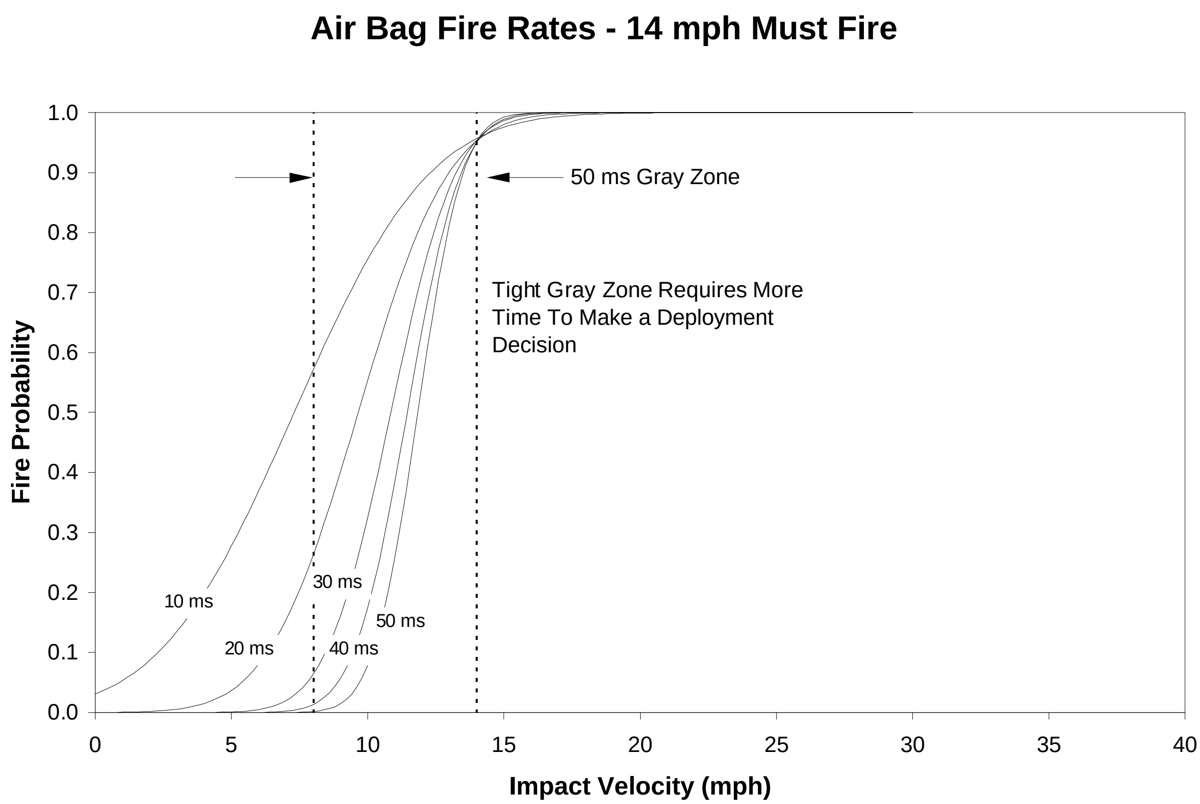

Figure 1. Air Bag Fire Rates for a 14 mph Must-Fire Threshold and the Corresponding Grey Zone.

There is an inherent trade-off between crash sensing confidence (or the probability of deploying an air bag at a specific speed relative to the pre-set must-fire threshold speed) and time to fire for an air bag system. This trade-off is the principal challenge in implementing a low risk deployment strategy. The trade-off is illustrated in Figure 1 where the air bag fire rates for a single stage air bag system with a 22 km/h (14 mph) must-fire threshold is shown. The probabilities of air bag firing are shown based on a model of vehicle crashes. The model was derived from actual impact data taken from a variety of DaimlerChrysler vehicles. The curves on this graph represent the probability that the air bag system will deploy the air bag for a particular impact velocity. The times noted on each of these curves represent the specified time-to-fire for a particular impact speed (in this case 22 km/h or 14 mph). This is the amount of time after the crash begins that the controller has available to make its deployment decision.

For example, if only 20 ms can be allowed to make a timely deployment decision in the 22 km/h (14 mph) must-fire condition, there is a probability that deployments will occur about 20 percent of the time in impacts with speeds as low as 13 km/h (8 mph), or lower. The reason for this is that the signal to noise ratio is high in the early stages of a crash as bumpers, sheet metal, structure and other components buckle and crush against one another. In about 20 percent of cases, the 20 ms sequence of sensor measurements from a 13 km/h (8 mph) crash appear as if they resulted from a 22 km/h (14 mph) crash. If 30 ms were allowable to make a deployment decision, the sensor measurements from a 13 km/h (8 mph) could be confused with a 22 km/hr (14 mph) crash in only about 7 percent of the cases. If 50 ms are allowable, virtually no 13 km/h (8 mph) crashes will be confused with 22 km/h (14 mph) crashes.

Figure 1 shows the fundamental challenge faced by an air bag controller: if a crash severity decision must be made very quickly based on limited information from the crash sensors, then there will be a large uncertainty in the inferred impact speed. The air bag controller uses measurements from sensors to estimate the speed of impact amidst noise and disturbances. A very small amount of uncertain data must be used to infer the impact speed. In the above example, a small percentage of deployments will occur at speeds as low as 8 km/h (5 mph) if only 20 ms are available to make a deployment decision. Conversely, if more time is taken to make a decision to fire, the uncertainty in impact speed is smaller. If there is a design requirement for a no-fire speed threshold of 13 km/h (8 mph), 50 ms will be required to make an air bag deployment decision.

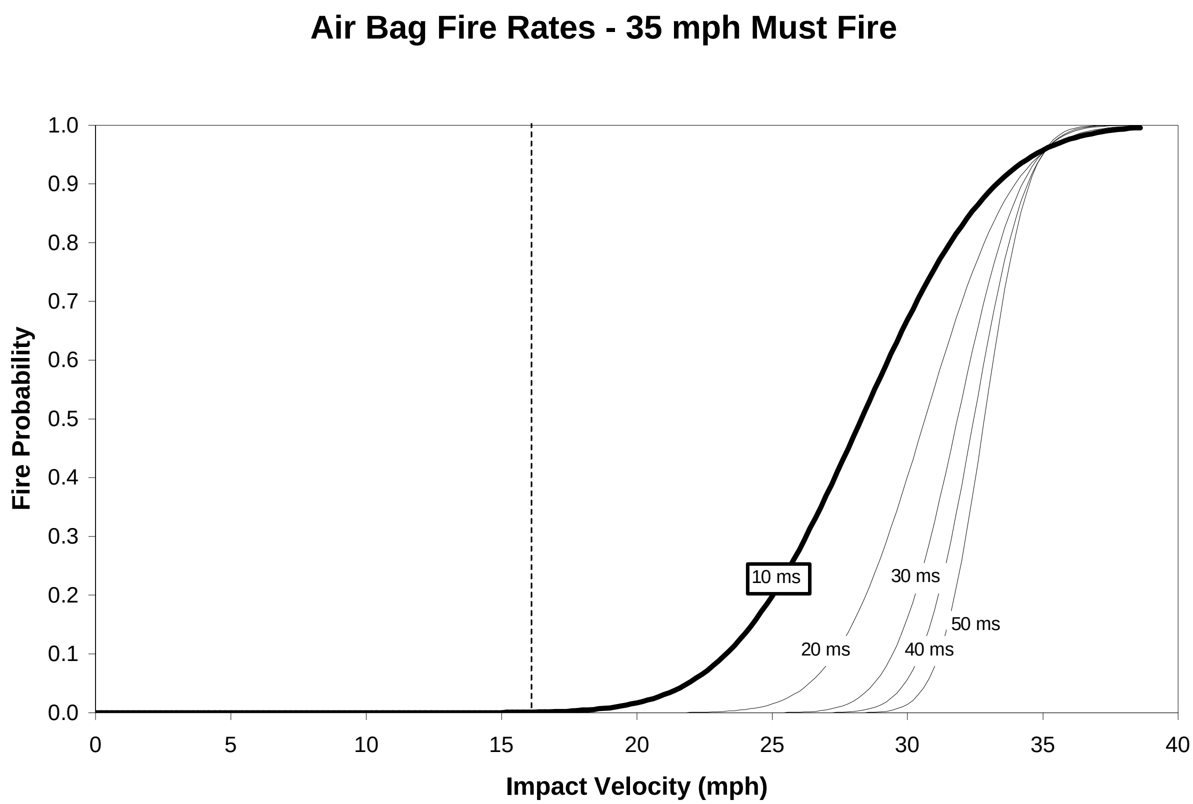

Figure 2. Air Bag Fire Rates for a 35 mph Must-Fire Threshold Based on Fire Time Specifications.

While longer decision times may be practical for relatively low speed impacts, very rapid decisions are required during high-speed crash events in order to limit occupant motion and allow time to inflate the air bag. Figure 2 illustrates the fire time distribution for a 56 km/h (35 mph) must-fire threshold. A 10 ms decision time best approximates the time to fire requirements for the second stage of a dual stage system at this impact speed. There is an approximately five percent probability of a second stage deployment at speeds as low as 32 km/h (20 mph) under these conditions. This situation is a consequence of needing to a make a rapid decision in the face of very little information about the crash event.

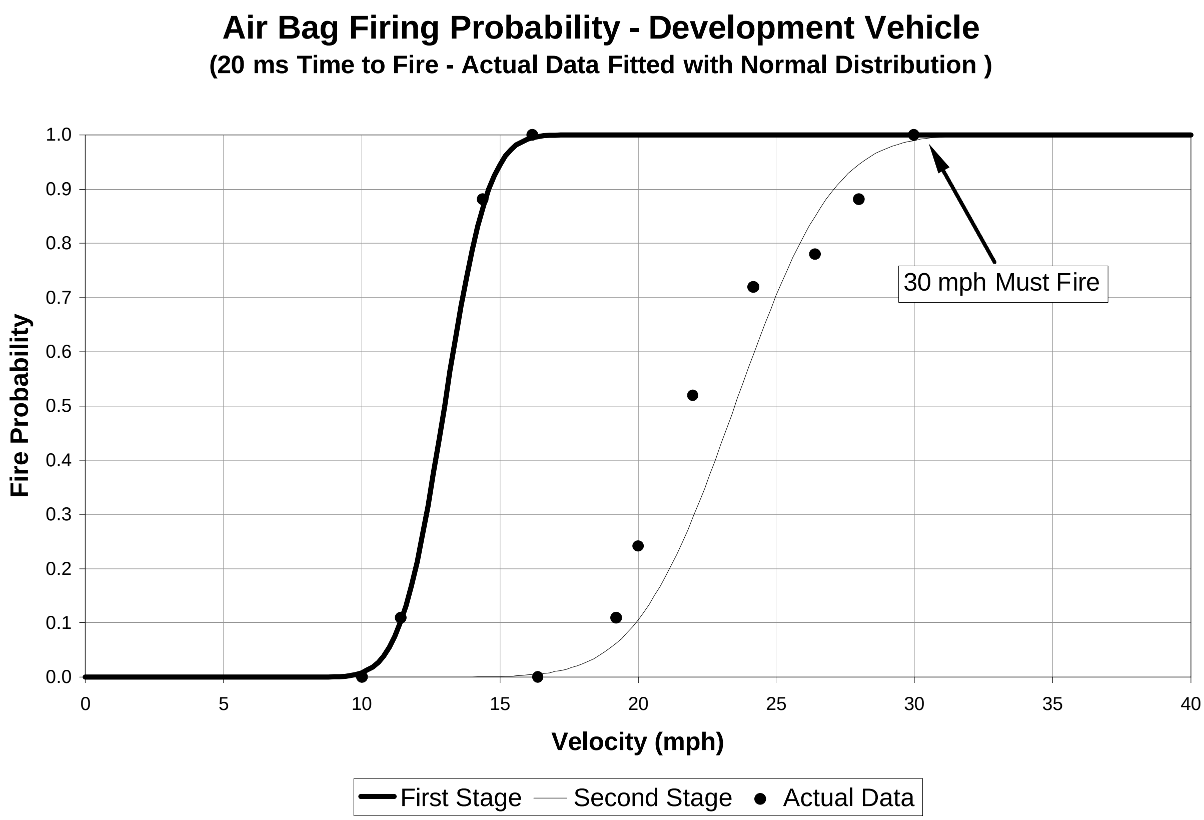

Figure 3. Air Bag Fire Rates for a Two Stage System in a Development Vehicle.

These probability distributions are consistent with DaimlerChrysler's experience with air bag systems in development vehicles. Figure 3 shows the first and second stage deployment probabilities in a development vehicle. The individually plotted points represent the actual distribution observed in development tests and the curves represent a modeled approximation. In this case, the second stage must deploy at 48 km/h (30 mph), but it is possible that it might deploy in some small number of cases at speeds as low as 29 km/h (18 mph).

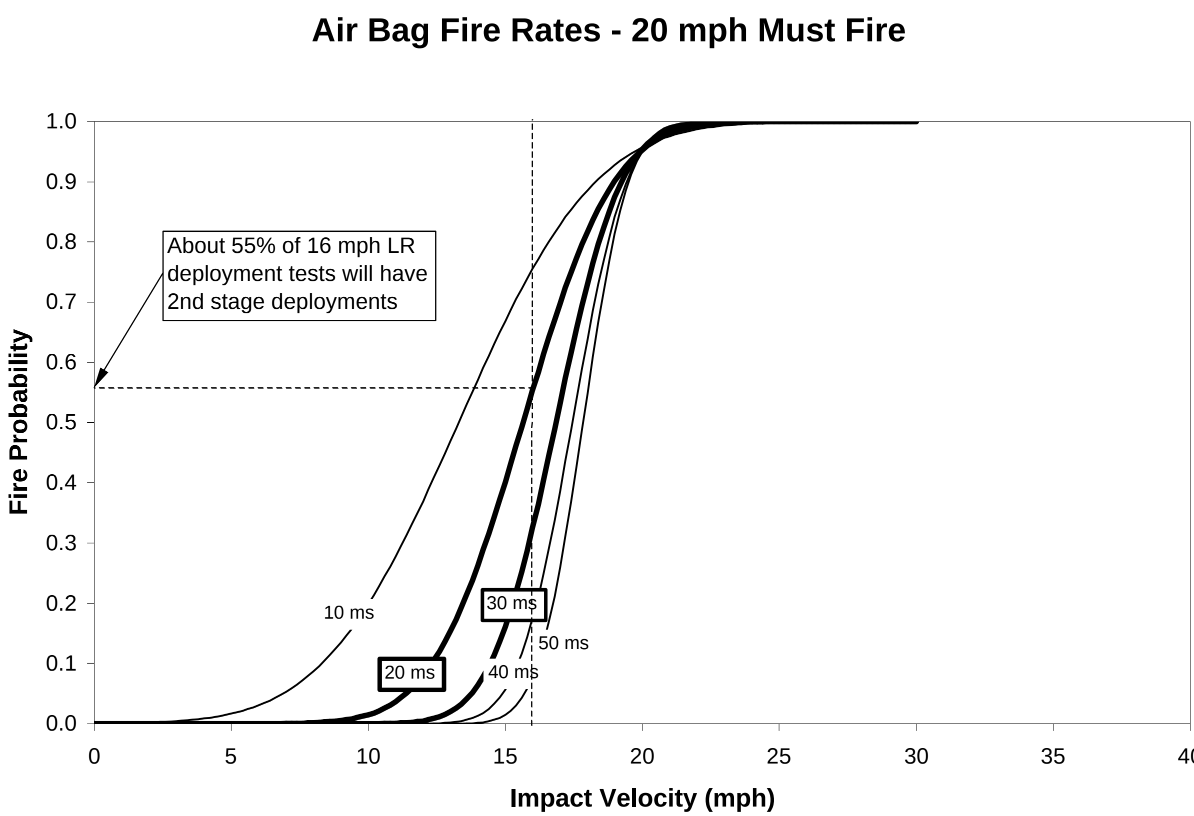

Figure 4. Risk of Deployment of Second Stage During a 16 mph Low Risk Deployment Test With a 20 mph Must-Fire Threshold

The consequence of the probability distribution of fire times on low risk deployment strategies can be seen in Figure 4. The fire rates are shown for a 32 km/h (20 mph) must-fire condition. A 20 ms fire time would be required in this situation. If the second stage of an air bag must be deployed at 32 km/h (20 mph) to assure compliance with a high-speed, unbelted test, there is an approximately 55 percent chance of deploying the second stage during the 26 km/h (16 mph) low risk deployment threshold test. This situation is for the best-case, theoretical distribution of fire rates. In the case of an actual development vehicle, the situation is likely to be worse.

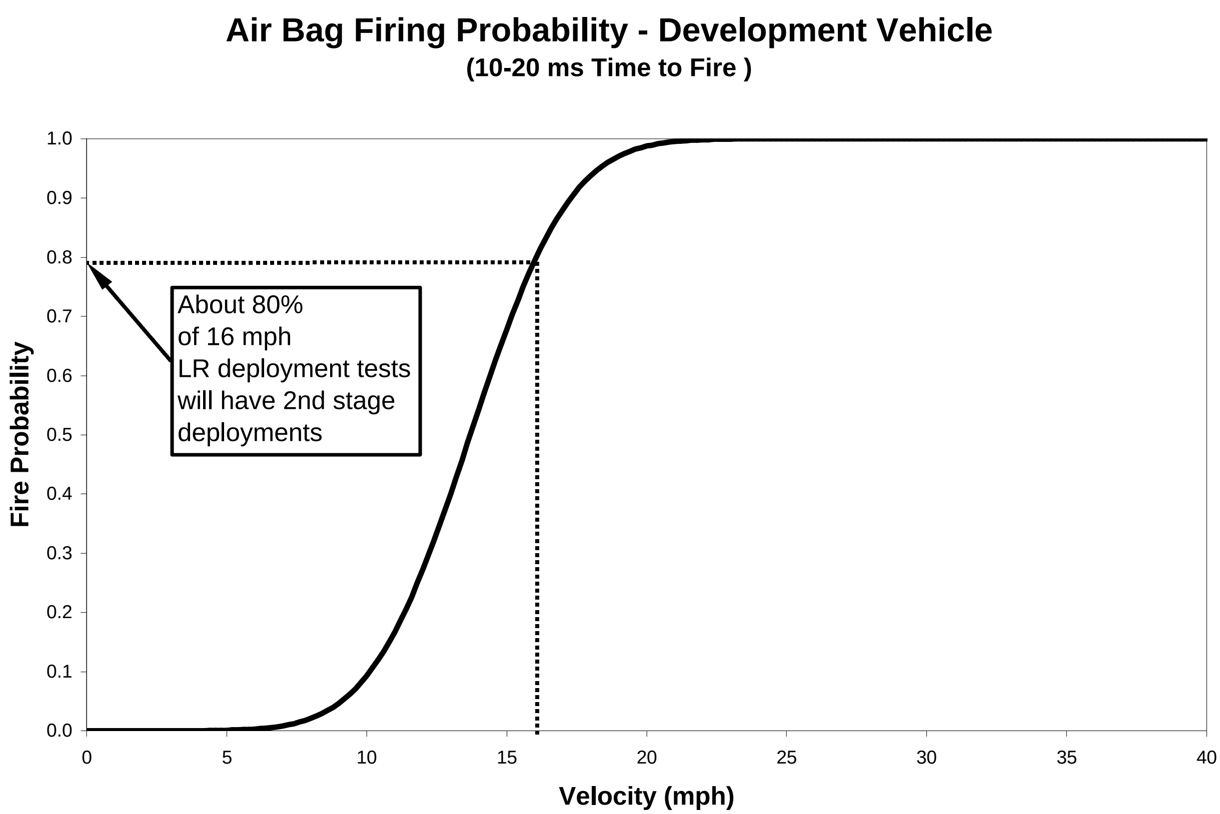

Figure 5. Risk of Deployment of Second Stage During a 16 mph Low Risk Deployment Test With a 20 mph Must-Fire Threshold in a Development Vehicle

Figure 5 shows the air bag firing probability for a development vehicle with a 10 - 20 ms fire time requirement. This curve was obtained from actual data and differs somewhat from the model shown in Figure 4. Under these conditions, the second stage of the air bag will be deployed in about 80 percent of cases at 26 km/h (16 mph). This would be an unacceptable risk. It is not possible to be certain that an unbelted 50^{th} male occupant is protected in a 32 km/h (20 mph) impact and simultaneously assure that the same air bag deployment (which will be too powerful to comply with low risk requirements) will not deploy during the 26 km/h (16 mph) low risk deployment threshold test. The separation of speeds between the low risk deployment threshold test and lowest speed at which the unbelted test is run raises serious reliability concerns.

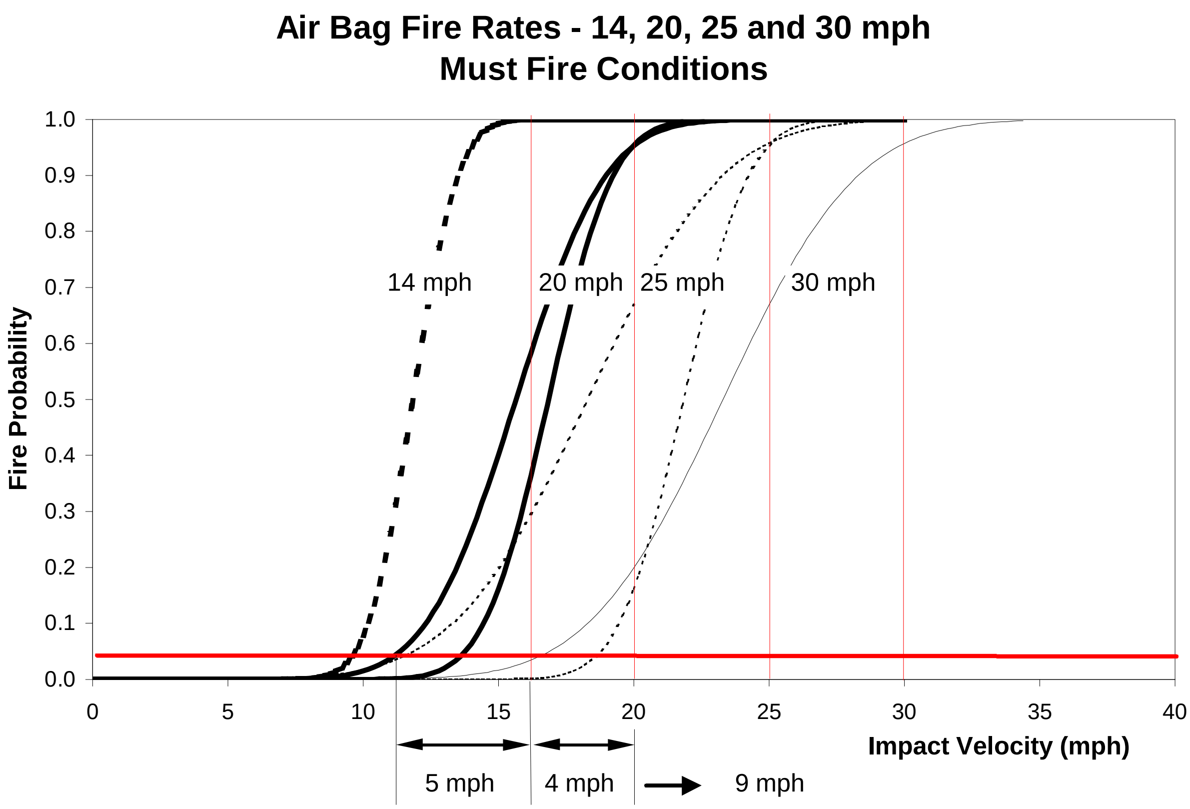

Figure 6. Risk of Deployment of Second Stage During a 16 mph Low Risk Deployment Test and the Speed Separation Requirement

The need for further separation between the test speeds for the low risk threshold test and the lower end of the range of speeds for the unbelted barrier tests is illustrated in Figure 6. The must fire conditions for 22, 32, 40 and 48 km/h (14, 20, 25 and 30 mph) are shown. The fire time requirements for each of these speeds is reflected in the distribution or range of distributions shown for each speed. In the case of the 32 km/h (20 mph) impact velocity (the lower bound of the high-speed, unbelted test), the low risk threshold test would result in an unacceptable risk of a second stage deployment instead of the desired low risk first stage deployment. In this situation, the threshold test would have to be conducted at a speed as low as 18 km/h (11 mph) in order to assure that the second stage would not deploy with an acceptably low level of risk.

However, a low risk threshold test is not appropriate at a speed of 18 km/h (11 mph) because this is lower than the speed where serious and fatal injuries to unrestrained occupants typically begin to occur. A more appropriate approach would be to maintain or slightly reduce the low risk deployment test speed while raising the lower bound of the high-speed unbelted test. This modification would help enable the implementation of low risk deployment strategies (especially in conjunction with changing the type of dummy used in the threshold test as discussed in

Section 1.2, below) while limiting inadvertent deployments and maintaining protection for unbelted occupants in high-speed impacts.

A trade-off exists between a narrow grey zone of deployment speeds and a short time to fire. A low risk deployment strategy must operate in a grey zone that is dictated by fire time requirements to limit the motion of the occupant at a particular speed of impact. Implementation of a low risk deployment strategy requires either a long time to fire in high-speed events (to limit the size of the grey zone) or a wider separation in speed between the low risk deployment threshold test and the lower bound of the high-speed unbelted tests. Since out-of-position risks preclude long decision times in high-speed events, the only viable alternative is to widen the separation of speeds.

Accordingly:

> **DaimlerChrysler petitions that the sections that define the threshold test for non-infant occupants (S22.4.4, S22.5.1, S24.4.4 and S26.4) and the sections that define the unbelted rigid barrier tests (S5.1.2(a)(2), S5.1.2(b) and S16.1(b)) be modified to provide a speed separation of 14 km/h (9 mph).**

2. Test Conditions for the Determination of Low Risk Deployment Air Bag Stage

In Section II.A., Key Provisions of the Rule (65 FR 30689), the Agency notes that advanced air bag systems can be designed to take many factors into account to determine the level of inflation provided to a given occupant in a crash:

> "With two levels of inflation, the vehicle manufacturer can design the air bag system so that the level of inflation is dependent on such factors as crash severity, *size and weight of the occupant, and position of the occupant*." (emphasis added)

In other words, the air bag that is deployed should be the right air bag for the occupant who is in the vehicle at the time of the crash.

When a manufacturer develops a low risk air bag system, the inflation stage of the low risk air bag stage is determined by its performance in static out-of-position (OOP) tests. These tests are performed with 5th percentile adult female dummies on the driver's side and child dummies on the passenger's side of the vehicle. These tests set an upper limit on the inflation level that the low risk air bag stage can have. The vehicle is then designed to always deploy this stage of the air bag in the crash test that is run to determine which air bag stage to deploy in the OOP tests (the "threshold test").

The only purpose of the threshold test is to determine which air bag stage to deploy in compliance static OOP tests. Dummies are seated in the vehicle during the threshold test to insure that an air bag will deploy (if one would under these crash conditions). This is necessary because some vehicles may not deploy an air bag if the control system recognizes an empty seat in the vehicle. Similarly, the dummies are tested without seatbelts since vehicles may vary the deployment level of the air bag based on the buckle status of the occupants, and unbelted occupants are most likely to be out-of-position in a crash.

The final rule requires the threshold tests to be performed with unbelted 50th percentile male dummies, in the mid-track position, on both sides of the vehicle. DaimlerChrysler's summary comments to the SNPRM recommended that the air bag stage which should be tested in OOP tests should be the stage of the air bag that would actually deploy for the same sized occupants in low speed crashes (i.e., all crashes at or below the threshold test speed). Specifically, DaimlerChrysler commented that:

> "... we recommend that the threshold compliance tests should not be conducted with 50th percentile male dummies, as currently proposed. Rather, they should be conducted with the specific driver (i.e., 5th percentile female) and passenger (3-year-old, 6-year-old or 5th percentile female[1]) for whom the static test will be conducted. This way, manufacturers are free to design air bag systems that can detect the size of the occupant and tailor the inflation level of the air bag to both the occupant's size and the crash severity. We note that this was exactly the Agency's intent when it revised the threshold compliance test proposal for the 12 month-old infant dummy. If the threshold compliance test is conducted as proposed, only the crash severity can be used to tailor the inflation of a low risk deployment air bag. Thus, we propose that a 5th percentile female should be seated in the driver position and one of the possible passengers, a 5th female or 3- or 6-year-old child dummy, should be seated in the passenger position for the threshold compliance test. All of the occupants should be ***unbelted*** for this test, to simulate the pre-out-of-position condition for these occupants (belted occupants are less likely to be severely out-of-position). The only criterion to be measured in these tests is the stage of the air bag that fires, since injury criteria will be properly assessed in the static tests." (emphasis added)

In the preamble to the final rule, the Agency did not address DaimlerChrysler's requested change in the test procedure for the low risk deployment threshold test. Instead, the comments only addressed the similar suggestion from the Alliance to use ***belted*** child and small adult dummies. In responding to this suggestion, the Agency objected to the proposal to use belted dummies, for the same reasons DaimlerChrysler suggested above. The Agency further explained that the 50th percentile male dummies should be used for this test because:

> "... while we are only testing the low risk deployment technology on the passenger side with three-year-old and six-year-old child dummies, a benign deployment in low speed crashes could provide ancillary benefits to larger occupants. We are concerned that using the child dummies to determine which stage or combination of stages of the air bag to deploy could unnecessarily limit the benefits of low risk deployment air bags."

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[1] DaimlerChrysler also commented that a low risk deployment requirement for the 5th percentile female on the passenger side should be included in the final regulation. The Agency agreed with this comment, but declined to include it in this final rule.

We believe that the Agency misjudged the effects of this decision. Given how such systems are designed to insure that they will comply with the regulation, it follows that:

- Because the vehicle is designed to always deploy the low risk air bag stage in the threshold test, and
- Because the low risk inflation stage is limited by the static OOP requirements for 5th percentile adult female and child dummies,
- Requiring the use of mid-size adult dummies for the threshold test requires the same level of inflation for larger occupants at the threshold test speed as for small adults (driver side) and children (passenger side).

Therefore, the test requirement effectively precludes tailoring the air bag output based on occupant classification or recognition. This test requirement essentially becomes "one size fits all" instead of "the right air bag for the occupant." By placing the mid-sized male dummy in the vehicle for the threshold test, the regulation prevents manufacturers from using additional information about the occupant such as size, weight or seat position, to determine which air bag inflation level to provide in a crash.

Finally, this procedure is inconsistent with the analogous procedure for determining the stage of the air bag to be tested with rear facing infant seats if the low risk deployment option is selected for 12-month-old infants. The preamble addressed industry concerns over the need to perform a 64 km/h (40 mph) rigid barrier crash with an infant seat in the passenger position in order to determine the air bag stage for these low risk deployment tests by observing:

> "Because the low risk deployment test is only conducted in the presence of a belted child restraint, a manufacturer that designed a system that always provided a lower level of deployment in the presence of a rear facing restraint could determine what level would deploy in a barrier crash test by means other than conducting barrier tests, e.g., by testing the sensor system that determined whether such a restraint was present."

The foregoing discussion recognizes that an air bag system could determine that a rear facing infant seat is present and then adjust the air bag inflation level accordingly. Yet, the final rule does not recognize that similar strategies could be designed for other occupants, namely child passengers and small drivers. DaimlerChrysler believes that such systems are feasible and should not be effectively prohibited by the requirements of the threshold test. Accordingly:

> **DaimlerChrysler petitions that the test requirements of the final rule, specifying that the non-infant low risk deployment threshold tests be performed with unbelted 50th percentile male dummies seated at the mid-track seating position be changed as follows:**
>
> **Modify S22.5.1 to require the threshold test to be conducted with an unbelted three-year-old test dummy seated in the passenger seat of the vehicle.**
>
> **Modify S24.4.4 to require the same test as specified in S22.5.1, except with an unbelted six-year-old dummy seated in the passenger seat of the vehicle.**

Modify S26.4 to require the threshold test to be conducted under the same conditions as the unbelted rigid barrier test in S16.1(b) with an unbelted 5th percentile female dummy seated in the driver seat of the vehicle.

3. Lack of Biomechanical Basis for N_{ij} Injury Criteria

We continue to believe that the N_{ij} criterion is not rigorously supported by the available test data as a good indicator of neck injury risk. DaimlerChrysler is submitting additional, new analyses further confirming that there is no justification that use of N_{ij} will minimize the likelihood of neck injuries. Also, problems with the Hybrid III dummy neck response to air bag loading call into question the validity of assessments such as N_{ij} which combine axial force and moment. The Agency has acknowledged issues with the neck design and the high moments that can occur with small rotations such as are seen in air bag loading. In particular, the Agency noted in Section XIII.J (65 FR 30729) that it was:

> "… uncertain whether this loading condition is biomechanically realistic."

Several commenters responding to the SNPRM have observed the high moment/low rotation conditions. DaimlerChrysler provided extensive data in its response to the SNPRM that showed that the Hybrid III dummy neck did not follow established biomechanical response corridors during air bag loading. Section XIII.J of the preamble responds to these findings:

> " However, none of the commenters, including DaimlerChrysler, provided the agency with additional data to justify or develop alternative neck response requirements that either verify the responses of the current Hybrid III design or provide the basis for improving it."

DaimlerChrysler included a technical paper, "Dummy Neck Response During Air Bag Loading and Injury Potential Assessment," in its response to the SNPRM (Docket No. NHTSA-99-6407-44). This paper provided data that showed that the neck response to air bag loading is due to non-biofidelic interactions between the air bag and the head/neck of the dummy. Furthermore, the paper presented two different head/neck structure modifications that prevented the unrealistic patterns of interaction. Also, the paper observed that NHTSA's THOR dummy did not appear to have the unrealistic interaction patterns and may offer an effective testing option if it were developed to a satisfactory level of usability.

The Agency has stated in Section VIII.B (65 FR 30718) that:

> "… we are adopting Nij as the best available neck injury criterion."

While DaimlerChrysler appreciates the need for a neck criterion in the standard, it disagrees with the conclusion that N_{ij} is the best criterion available. The investigation described in the attached paper "Studies of Neck Injury Criteria Based On Existing Biomechanical Test Data" (Appendix A) indicates that the use of moment (such as it is used in the N_{ij} criterion) is not supported by the biomechanical data used to form the basis for such criteria.

The results showed that using neck axial force alone is the best indicator of injury. N_{ij} and other criteria that combine tension and moment are actually *less effective* in predicting injury than axial force alone. The axial force and moment data were examined for correlation with injury prediction using variety of standard statistical techniques. All indications are that increasing the weight given to moment (from zero) decreases the accuracy of the prediction. Moment is a random variable in the biomechanical data set. This effect can be seen in Figure 7. The peak values of axial force and moment are shown for the test series used as a basis for N_{ij}. The horizontal axis shows the tension (positive-valued axial force) since none of the injuries were associated with peak values of compression.

Paired Animal/Test Dummy Air Bag Deployment Tests for Neck Injury Potential (Porcine Animal Subject and Three Year Old Test Dummy)

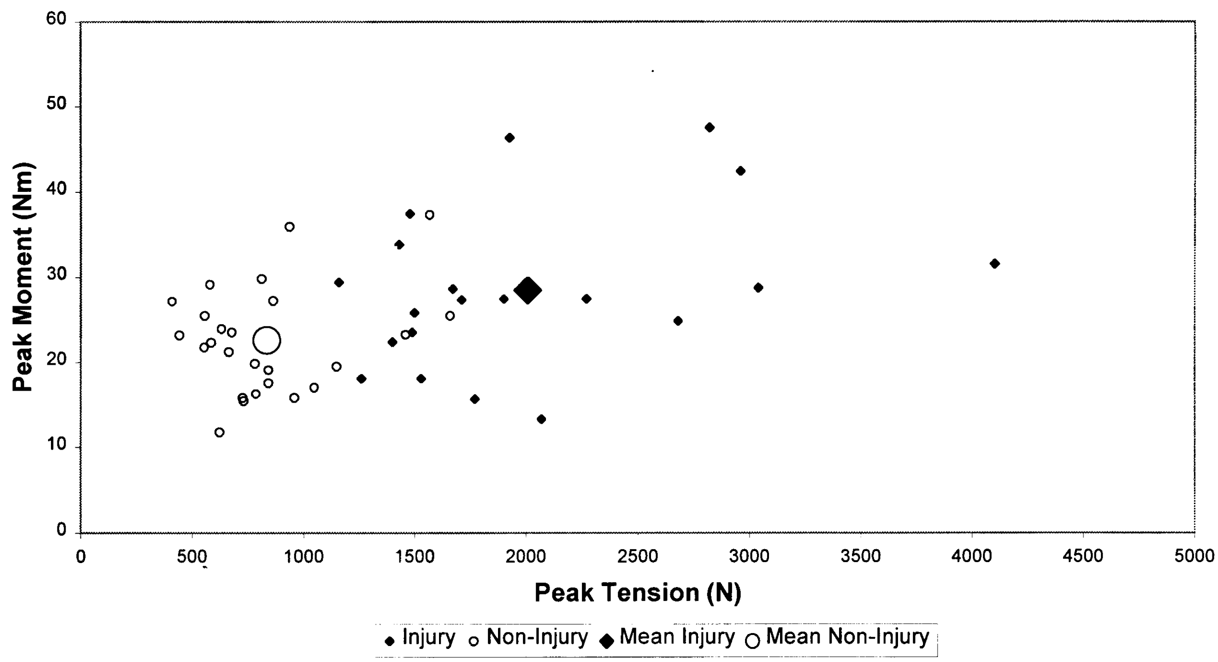

Figure 7. Scatter Plot of Biomechanical Tension and Moment Data.

With the currently available test data and anthropomorphic test devices, only neck axial force is a reliable predictor of injury potential. A direct fit optimization analysis was applied to re-examine the constants used in the N_{ij} criterion. The results show that no values of the constants used in the N_{ij} criterion corresponding to compressive force, extension moment and flexion moment will optimally separate the injury and non-injury cases in the biomechanical data set. Only the tensile intercept allows optimal identification of the injury risk. With the currently available test data and anthropomorphic test devices, only neck tension is shown as a reliable predictor of injury potential. While not supported by this data, it is recognized that other studies have shown compressive axial force is also a controlling variable in neck injury.

The use of N_{ij} is also likely to have unintended consequences. The neck assessment values in the final rule may induce manufacturers to either decrease the size of air bags or increase air bag power levels from what is necessary for real-world occupant protection. The neck assessment values have the effect of requiring a rapid deployment of the air bag (i.e., higher power or smaller volume) to create membrane tension prior to the test dummy interacting with the air bag. This condition evenly loads the head and chest of the test dummy during impact and limits the moment on the neck caused by differential loading of the head and chest. It also prevents the non-biofidelic interaction modes (e.g., the air bag catching behind the jaw of the test dummy) documented in DaimlerChrysler's response to the SNPRM described above. The unproven neck assessment values may result in air bag designs that are driven by limitations in the Hybrid III dummy neck design rather than for protection of the driving public.

> **Consequently, DaimlerChrysler petitions the Agency to reconsider its decision to specify N_{ij} as an injury criterion and instead adopt only neck axial force (tension and compression) as the sole criteria for assessing potential for neck injury.**

4. Additional Technical Issues

4.1 Inconsistent use of Scaling Laws to Establish Injury Criteria of Smaller Test Dummies

The scaling relationships which relate the injury criteria for a 50th percentile male Hybrid III dummy to other size dummies should be consistently applied to the 5th percentile female. In its comments to the SNPRM, the Alliance agreed with the Agency that it is appropriate to scale the proposed 50th percentile adult male HIC limit of 700 for the Hybrid III three-year-old and 12-month-old CRABI dummies. Using the same rationale, the Alliance commented that this relationship should be applied to the adult female and six-year-old child dummies for consistency of analysis.

The Agency did not accept the Alliance proposed limits in the final rule and instead chose to adopt the original proposed limit of 700 for both the adult female and the six-year-old. The Agency notes in the final rule (Section IX.A, 65 FR 30717) that:

> "... AAM recommended that we adopt somewhat higher limits than we proposed for the 5th percentile adult female dummy (779 rather than 700) and the 6-year-old child dummy (723 rather than 700). That organization argued that we were not being consistent in applying scaling relationships from the 50th percentile adult male dummy to the other dummies.
>
> After considering the comments, we have decided to adopt the limits we proposed. We note that the data from which the HIC relationship was developed represented an elderly

> adult population[2]. There is no basis to assume that the population had the dimensions of 50th percentile adult males. We believe it is reasonable to apply the same 700 HIC limit to all persons who may be represented by the original data set, including 5th percentile adult females and 50th percentile adult males."

We believe the Agency applied incorrect assumptions to the data. While it is correct to assume that the data set represents elderly individuals, as, in fact, is the case, it is not correct to assume that the data is unrepresentative of the 50th percentile adult male. When consulting the referenced data from the paper by Hodgson and Thomas (cited above), proof is found that the population does in fact have the dimensions of 50th percentile adult males.

HIC is based on data for the 6 cadavers in the Hodgson and Thomas study. This data can be compared to the 50th percentile adult male anthropometry published in a study done by UMTRI and reported in 1983 as a Final Report to NHTSA numbered DTNH22-80-C-07502 by Robbins, et al. The data can be examined in a number of ways. While a rigorous statistical analysis is precluded by the fact that there are too few subjects and there are no statistics such as standard deviations for the UMTRI data, some general comments can still be made. If one examines the anthropometric data for the head, including circumference, antero-posterior depth, lateral breadth, and head weight in addition to the overall stature data; one can see the following:

Qualitative Observations:

- 3 of 6 subjects had head antero-posterior depth the average male as defined by UMTRI.
- 4 of 6 subjects had stature = the average male as defined by UMTRI.
- 4 of 6 subjects had head circumference = the average male as defined by UMTRI.
- 4 of 6 subjects had head breadth = the average male as defined by UMTRI.
- 5 of 6 subjects had head weight = the average male as defined by UMTRI.
- (We can assume that we can ignore the total body weight based on probable illness prior to death)

Additional Observation:

- If one looks at the average and standard deviations of the anthropometric measurements from the Hodgson and Thomas study in comparison to the values from the UMTRI study, it is difficult to assess that there would be any statistically significant differences between them.

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[2] Hodgson, V.R. and Thomas, L.M.: "Comparison of Head Acceleration Injury Indices in Cadaver Skull Fracture", Proceedings of the Fifteenth Stapp CarCrash Conference, SAE Technical Paper Number 710854, 1971.

Given the above analysis of the Hodgson and Thomas data, the subjects used as a basis for HIC were representative of the 50th percentile adult male population. Therefore, the HIC for the 5th percentile adult female and six-year-old child dummies should be scaled as other dummy measures have been. Accordingly:

> **DaimlerChrysler petitions that the HIC for the 5th percentile adult female and six-year-old child dummies should be scaled as other dummy measures have been. A limit of 779 should be adopted for the 5th percentile female test dummy and a limit of 723 should be adopted for the six-year-old child dummy.**

In its SNPRM response, the Alliance provided comments on the Agency's proposed thoracic acceleration limits. Although the Alliance maintained the viewpoint that thoracic acceleration is not a unique predictor of thoracic injury risk, it supported the values that it proposed in Attachment C of its SNPRM comments. Most of the limits proposed in Attachment C mirrored those proposed by the Agency with the exception of the adult female limit of 60 g's. The Agency proposed that this limit should be the same as the one proposed for the adult male. Consistent with the Alliance comments on HIC, that the limits should be based on scaling, and such scaling should be applied to all sizes and ages of dummies, the Alliance suggested that the Agency adopt a limit of 73 g's for the adult female. However, NHTSA declined to accept the Alliance proposal.

In its final rule (Section IX.A 65 FR 30717), the Agency states:

> "After considering the comments we are adopting the proposed 60 g's chest acceleration limit for the 5th percentile adult female dummy. AAM's recommended chest acceleration limit of 73 g's for this dummy was obtained using scaling procedures that only considered the effects of the geometric differences between 50th percentile adult males and 5th percentile adult female. However, we believe the additional effect of decrease in bone strength for the more elderly population at risk in out-of-position situations should also be taken into account."

Most people when asked would agree that the strength of female bones decreases with age much more than does the strength of male bones. However, this concept appears to be true only when one considers the overall resulting performance, as the actual strength does not appear to change differently for females than males. Mosekilde and Mosekilde[3], Ruff and Hayes[4], and Martin and Atkinson[5] have all shown that bone material strength in both males and females declines equally with age. However, the bones of males showed changes in other properties (e.g., geometric) that compensated for the loss in strength while females did not.

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[3] Mosekilde, L. and Mosekilde, L.: "Sex differences in age-related changes in vertebral body size, density and biomechanical competence in normal individuals", Bone, Vol. 11:67-73, 1990.

[4] Ruff, C.B. and Hayes, W.C.: "Sex differences in age-related remodeling of the femur and tibia", J. Orthop. Res., Vol. 6:886-896, 1988.

[5] Martin, R.B. and Atkinson, P.J.: "Age- and sex-related changes in the structure and strength of the human femoral shaft", J. Biomechanics,Vol.10:223-231, 1977.

Currey[6] showed that the mechanical properties of bone tissues vary greatly with greatly differing functions. While Granik and Stein[7] reported the stress at failure of human ribs, there is very little data on the strength of ribs as a function of age or sex[8].

Using data from Eppinger[9], it is found that the number of rib fractures sustained under nominally similar belt loads (and assumed similar test conditions) increases at essentially the same rate for males and females. This may be because, as noted above, the mechanical properties of bone are very dependent on the function of the bone. Ribs perform the same function in males and females and are not weight-bearing members of the skeleton to the same extent as vertebral bodies or femora. It is reasonable to assume that ribs would be less likely to be influenced by any differences in occupation or gender-related activities between men and women.

From the above analysis, the Agency's conclusion that the "decrease in bone strength for the more elderly female population … should also be taken into account" is not supported by the available biomechanical technical literature. The literature indicates that the acceleration tolerance of the small female can be scaled directly from the mid-sized male value because the elderly female tolerance appears to be no different from the elderly male tolerance.

Furthermore, an unintended consequence of using an adult female acceleration limit of 60 g's may be the further repowering air bags. Initial belted test data shows that current systems are producing 5th percentile female test dummy thoracic acceleration numbers that, although below the 60 g limit in most cases, do not have adequate compliance margins. In order to lower the thoracic accelerations, manufacturers may be forced to lower the output of seat belt load limiters. If the seat belt load limiters were reduced, the air bag would need to become more aggressive in order to protect the 50th percentile adult male in belted 56 km/h (35 mph) crash tests. Increased venting and porosity may be necessary to control the displacement of the 5th percentile female dummy and the associated chest acceleration. However, both of these options may force manufacturers to have deployments that are more aggressive. Furthermore, punch-through may occur while restraining large occupants. Limiting the 5th female chest acceleration to 60 g will force trade-offs in the design of the air bag system that will reduce the quality of safety. Therefore:

> **DaimlerChrysler petitions that the chest acceleration limit for the 5th percentile adult female be scaled as other dummy measures have been and a limit of 73 g be adopted.**

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[6] Currey, J.D.: "Mechanical properties of bone tissues with greatly differing functions", J. Biomechanics, Vol. 12:313-319, 1979.

[7] Granik, G. and Stein, I.: "Human ribs: static testing as a promising medical application", J. Biomechanics, Vol. 6:237-240, 1973.

[8] Zhou, Q., Rouhana, S.W., and Melvin, J.W.: "Age effects on thoracic tolerance", Proceedings of the 40th Stapp Car Crash Conference, SAE Technical Paper Number 962421, 1996.

[9] Eppinger, R.H.: "Prediction of thoracic injury using measurable experimental parameters", Proceedings of the 6th International Conference on Experimental Safety Vehicles, 1976.

4.2 Lack of Notice and Opportunity to Comment Issues

<u>4.2.1 Changes to Instrumentation Requirements</u>

While the move to phaseless filters is consistent with SAE J211 and technically feasible, implementation of this change requires non-trivial modifications to software that could not be completed by the effective date of the revised regulation (June 12, 2000). The requirement to use phaseless filters and associated other changes to the existing FMVSS 208 regulation were not included in either of the previous notices of proposed rulemaking. Therefore, manufacturers did not have sufficient notice to either comment upon or anticipate the requirement to implement these changes.

DaimlerChrysler petitions the Agency to reconsider the effective date of phaseless filter data beginning with the 2002 model year. This would eliminate the need to reprocess completed compliance data for the 2001 model year, which is currently about to begin production.

> **DaimlerChrysler petitions for the following modifications to the regulatory text, and that these modifications should be effective June 12, 2000:**
>
> **S 4.13 <u>Effective September 1, 2001,</u> all data channels used in injury criteria calculations shall be filtered using a phaseless digital filter, such as the Butterworh four-pole phaseless digital filter specified in Appendix "C" of SAE J211/1 rev. Mar 95, incorporated by reference in S4.7.**
>
> **S13.1 Instrumentation for Impact Test Part 1 Electronic Instrumentation. Under the applicable conditions of S8, mount the vehicle on a dynamic test platform at the vehicle attitude set forth in S13.3, so that the longitudinal center line of the vehicle is parallel to the direction of the test platform travel and so that movement between the base of the vehicle and the test platform is prevented. The test platform is instrumented with an accelerometer and data processing system having a frequency response of 60 channel class as specified in SAE J211/1 rev. Mar 95 (see S4.7). The accelerometer sensitive axis is parallel to the direction of test platform travel.<u> The test is conducted as follows:</u>**
>
> **<u>(a) Before September 1, 2001: The total change in velocity (Delta V) shall be determined from the integration of the entire acceleration versus time curve from the sled. The Delta V shall include the period of time in which the sled is accelerating to 0.5 g. All points on the acceleration versus time curve at and beyond 0.5 g must be contained within or on the corridor defined in Figure 6. The Agency may shift the curve with respect to time in order to fit the curve within the corridor.</u>**
>
> **<u>(b) After September 1, 2001:</u> Conducted at velocity change approximating 48 km/h (30 mph) with acceleration of the test platform such that all points on the crash pulse curve within the corridor identified in Figure 6 are covered. An inflatable**

> **restraint is to be activated at 20 ms +/´2 ms from the time that 0.5 g is measured on the dynamic test platform. The test dummy specified in S8.1.8, placed in each front outboard designated seating position as specified in S10, excluding S10.7, S10.8, and S10.9, shall meet the injury criteria of S6.1, S6.2(a), S6.3, S6.4(a), S6.5, and S13.2 of this standard.**

4.2.2 Change in Duration of Application of Dummy Containment Criteria

The existing dummy containment criterion of FMVSS 208 is contained in S6.1, which states: "All portions of the test dummy shall be contained within the outer surfaces of the vehicle passenger compartment throughout the test." The SNPRM did not expressly propose to change this criterion, rather it only proposed extending this criterion to other sections of the regulation. In the preamble to the SNPRM (64 FR 60595), the Agency provided the following discussion of time duration for the purposes of measuring injury criteria:

> "We have decided to propose specific end points for measuring injury criteria in both crash tests and low risk deployment tests in order to resolve any uncertainty on the part of vehicle manufacturers and NHTSA as to when the measured injury criteria are relevant. ... Regardless of the time frame used to measure other injury criteria, all dummies would continue to be required to remain fully contained within the test vehicle until physically removed by a technician."

The proposed regulatory text included changes to section S6.1, and new language to be included in sections S15.3.1, S19.4.1, S21.5.1 and S23.5.1. Each of these sections was proposed to require:

> All portions of the test dummy [and child restraint][10] shall be contained within the outer surfaces of the vehicle passenger compartment.

No proposal was included to define further the duration of this assessment, and it was assumed by DaimlerChrysler that the existing "throughout the test" time period still applied. The final rule, however, adopted a previously unproposed requirement in S4.11(b): "The requirements for dummy containment shall continue until both the vehicle and the dummies have ceased moving." This requirement goes beyond the current requirements of FMVSS 208.

DaimlerChrysler does not have processes in place in our test laboratories to record the movement of the vehicle until it and its occupants have ceased moving. Typical filming of the crash event ceases at about 500 milliseconds (1/2 second) after the time of impact. The vehicle may not be completely at rest for one or more seconds after impact and the vehicle may move out of the cameras' viewing frames during this time. To require manufacturers to record this longer duration event will require new equipment and will increase the size of data files that must be stored to document vehicle compliance, but will result in negligible safety benefits.

[10] The addition "and child restraint" applied only to S19.4.1.

> **DaimlerChrysler petitions for the removal of S4.11(b) because this modification to FMVSS 208 was not proposed as part of either the NPRM or SNPRM. Since the modification has no demonstrated benefit or safety need, and has unforeseen negative consequences, and since manufactures were not given prior notice of this change, it should not have been included in the final rule.**

4.3 Telltale Visibility Requirements

The requirements of S19.2.2(d) forbid the telltale to be located in a position "on or adjacent to a surface that can be used for temporary or permanent storage where use of the storage space could obscure the telltale from either the driver's or right front passenger's view." These requirements could be met, according to the Agency (65 FR 30723), by a telltale " located on the cover to the glove compartment, or by the rearview mirror, but could not be located behind a cup-holder." While these requirements may be sufficient when a forward facing occupant is seated in the right front passenger seat, *they are insufficient to insure that the telltale is visible when a rear facing infant seat is installed.* Since this is a situation where it is critical for the driver to know whether the air bag is suppressed, DaimlerChrysler believes that the text of this section needs to be revised.

> **DaimlerChrysler petitions that S19.2.2(d) be revised as follows:**
>
> **... and shall not be located on or adjacent to a surface that can be used for temporary or permanent storage where use of the storage space could obscure the telltale from either the driver's or a forward facing right front passenger's view, or where the telltale would be obscured from the driver's view if a rear facing child restraint is installed in the right front passenger's seat.**

The requirements of S19.2.2(e) specify that the telltale must be visible to the "right front passenger" under all driving conditions. This requirement should only apply to *forward facing* passengers in the right front passenger seat, and should also be consistent with the requirements of section 5.3.4(b) FMVSS 101 for dimmable telltales.

> **DaimlerChrysler petitions for the following modification to S19.2.2(e):**
>
> **(e) Shall be visible to the driver and forward facing right front passenger under all driving conditions. ... The means for providing the required visibility may be adjustable manually or automatically, except that the telltale(s) may not be adjusted under any driving conditions to a level that is not visible**~~, e.g., to the nighttime intensity during daytime driving conditions~~**.**

4.4 Telltale Labeling Options

S19.2.2 requires the telltale to be identified with the words "PASSENGER AIR BAG OFF" either on or near the telltale. The use of a text identifier presents difficulties for vehicles which are marketed in countries where English is not the primary language, or where dual language identifiers are required. Other controls in the vehicle are identified using standard "ISO Symbols" in order to reduce this complexity. Figure 8, below is an example of such a symbol.

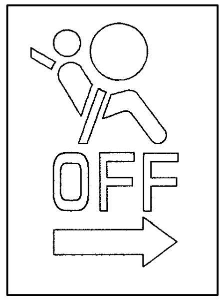

Figure 8. Example ISO Symbol

> **DaimlerChrysler petitions that S19.2.2 be revised to allow for the use of an optional ISO symbol to replace the textual identification for the passenger air bag telltale.**

4.5 Inconsistency in Definition of Belted Child Seat Tests for Child Seats Equipped with Child Restraint Anchorage Systems ("LATCH")

There is an apparent inconsistency between the provisions for "belted" tests with child restraints in the general provisions sections for 12-month-old, three-year-old and six-year-old child dummies (S20.1.6, S22.1.3 and S24.1.3) and the test procedures which follow each of these sections. Specifically, the three general requirements sections specify:

> "Except as otherwise specified, if the [child restraint system][11] has an anchorage system as specified in S5.9 of FMVSS No. 213 and is tested in a vehicle with a right front outboard vehicle seat that has an anchorage system as specified in FMVSS No. 225, the vehicle shall comply with the belted test conditions both with the restraint anchorage system attached and unattached to the vehicle seat anchorage system and with the unbelted test conditions with the restraint anchorage system unattached to the vehicle seat anchorage system."

As written, this paragraph appears to imply that the vehicle should be tested with <u>both</u> the vehicle's belt system <u>and</u> the LATCH attachments securing the child restraint in the vehicle seat for the belted tests. This is in conflict with the intentions of the Agency cited in the preamble (65 FR 30712) that "Standard No. 213 does not contemplate seating systems where both the safety belt and the lower anchor attachments are used." Finally, all of the subsections following these three general requirements sections specifically say, "do not attach the vehicle safety belt."

> **To clarify these requirements, DaimlerChrysler petitions for the following modifications to S20.1.6, S22.1.3 and S24.1.3:**

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[11] Each section specifies the type of restraint or restraints that are appropriate for that size child dummy. The rest of the paragraph is identical in all three places in the regulation.

> **Except as otherwise specified, ... the vehicle shall comply with the belted test conditions ~~both~~ with the restraint anchorage system attached to the vehicle seat anchorage system and the vehicle seat belt unattached. It will also comply with the belted test conditions with the restraint anchorage system unattached and the vehicle seat belt attached. ~~and unattached to the vehicle seat anchorage system and~~ The vehicle will comply with the unbelted test conditions with the vehicle seat belt unattached and the restraint anchorage system unattached to the vehicle seat anchorage system.**

4.6 Need to Test Child Restraints with Tethers Attached

Sections S20.1.7, S22.1.4 and S24.1.4 all require "Do not attach any tethers." While this may be the worst case condition for use of the child restraint, this is not necessarily a worst case condition *for detecting the presence of the child restraint.* A tightly cinched tether anchor could increase the apparent weight of the child restraint read by a weight sensing system. Furthermore, if the tether anchor is attached, a cinching force must be specified to make this test condition repeatable. DaimlerChrysler recommends adopting the same cinching force range used to test child restraints to the requirements of FMVSS 213.

> **Thus, DaimlerChrysler petitions that the following text replace the existing text in these sections:**
>
> **If the child restraint has a tether attachment, and the vehicle seat has a tether anchorage meeting the requirements of FMVSS 225, the vehicle shall comply in belted tests with the child restraint facing forward with the tether attached and unattached. Cinch the webbing to a tension of not less than 53.5 N and not more than 67 N, to secure the top of the child restraint. Measure belt tension in a flat, straight section of the tether strap between the child restraint and the tether anchorage on the vehicle seat.**

5. Technical Corrections

DaimlerChrysler petitions that each of the following technical corrections be made to the regulatory text, effective retroactively on the date of its enactment, June 12, 2000.

Note: in each case, needed additions to the text are underlined, and deletions are struck through.

5.1 Owner's Manual Information

The requirements of S4.5.1(f)(2)(iv) and S4.5.1(f)(2)(vii) should apply only to vehicles that are equipped with suppression systems. The advanced air bag requirements of sections S19, S21 and S23 allow the use of suppression systems *as one option* to provide protection for 12-month-old infants in rear facing infant seats, three-year-old and six-year-old children, respectively. These sections also include options for low risk deployment air bags that do not employ suppression technology to provide protection for these occupants. Thus, the requirements to provide information about the suppression system and the operation of the telltale lamp do not apply to vehicles that do not have suppression systems as part of their advanced restraint system.

The following changes need to be made to clarify the applicability of these sections of the regulation:

> **DaimlerChrysler petitions for the following modifications to the regulatory text:**
>
> **(iv) <u>for vehicles certified to meet the requirements of S19.2, S21.2 or S23.2,</u> a complete description of the passenger air bag suppression system installed in the vehicle, including a discussion of any suppression zone.**
>
> **(vii) <u>for vehicles certified to meet the requirements of S19.2, S21.2 or S23.2,</u> a discussion of the telltale light, specifying its location in the vehicle and explaining when the light is illuminated.**

5.2 Incorrect Section Reference

The reference to S4.10 in sections S6.6(a)(1), S15.3.6(a)(1), S19.4.4(a)(1), S21.5.5(a)(1), S23.5.5(a)(1), and S25.4(a)(1) is incorrect. In each case, the reference should be to S4.11, which describes the time period over which the injury criteria should be calculated.

> **DaimlerChrysler petitions that the above referenced sections be revised to refer to S4.11, instead of S4.10.**

5.3 Inconsistent Text

The text in S15.3.4 is inconsistent with similar requirements elsewhere in the regulation. The text should mirror similar sections in the regulation (e.g., S21.5.4 and S23.5.4).

> **DaimlerChrysler petitions for the following modification to the regulatory text:**
>
> **S15.3.4 Compression deflection of the sternum relative to the spine, as determined by instrumentation,** ~~shown~~ **shall not exceed 52 mm (2.0 in).**

5.4 Lack of Repeatability - Seat Position Adjustment Procedure

Raising a seat to mid position front and rear can cause variation in the cushion angle in many vehicle models, as there is often a switch that controls cushion angle independently of the vertical adjustment. Because of this, it is possible to meet the mid-vertical requirements of S16.2.10.1.1 with a variety of cushion angles, thus reducing the repeatability of the test requirements. The seat angle should instead be established with the seat full forward, in the full down height position.

DaimlerChrysler petitions for the following modifications to the regulatory text:

S16.2.10.1.1 If a seat is adjustable in the fore and aft and/or vertical directions, move the seat to the forwardmost seating position and ~~mid-height~~ **full down height position. Adjust the cushion angle as required to achieve the furthest down position.**

S16.2.10.1.4 Adjust the seat vertically as close to the mid-height position as possible, while maintaining the cushion angle established in S16.2.10.1.3. as close as possible. ~~If possible, maintain the seat cushion reference angle measured in the middle and full forward condition in S16.2.10.1.3.~~

5.5 Driver Foot Positioning

The procedure for positioning the left foot of the 5^{th} percentile female dummy in S16.3.2.3 is inconsistent with the procedure for positioning the foot of the 50^{th} percentile male dummy in S10.6.1.2. Specifically:

- There is no preclusion for placement of the foot of the 5^{th} percentile female dummy to the wheel well similar to that for the 50^{th} percentile male dummy. This requirement should be consistent.
- The foot position specified for the 5^{th} percentile female dummy is not the normal rest position of the foot. The requirement for the foot position for the 50^{th} percentile male dummy is more consistent with actual driver position and should be used with the 5^{th} percentile female dummy.
- If a foot rest is provided, the foot of the 5^{th} percentile female dummy should be allowed to be positioned on it, as this is allowed for the 50^{th} percentile male dummy.

DaimlerChrysler petitions for the following modifications to the regulatory text:

S16.3.2.3.3 Place left foot on the toe-board with the rearmost point of the heel resting on the floor pan as close as possible to the point of intersection of the planes described by the toe-board and floor pan, and not on the wheel-well projection.

S16.3.2.3.4 If the foot can not be positioned on the toe-board, set it initially perpendicular to the lower leg and place it as far forward as possible with the heel resting on the floor pan.

S16.3.2.3.5 If necessary to avoid contact with the vehicle's brake or clutch pedal, rotate the test dummy's left foot about the lower leg. If there is still pedal interference, rotate the left leg outboard about the hip the minimum distance necessary to avoid the pedal interference. For vehicles with a foot rest that does not elevate the left foot above the level of the right foot, place the left foot on the foot rest so that the upper and lower centerlines fall in a vertical plane.

~~If the left foot does not touch the floor pan, place the foot parallel to the floor and place the leg as perpendicular to the thigh as possible.~~

5.6 Passenger Seat Position - Bench Seats

Further clarification of the seating position for testing vehicles with 100 percent bench seats is needed. As currently specified, moving the seat forward to position the passenger dummy may change the position of the bench seat for the driver dummy.

DaimlerChrysler petitions for the following modifications to the regulatory text:

S16.3.3.1.8 Before proceeding,

(a) for individually adjustable front seats: Attempt to return the seat to the full forward position, if it has been moved from that location as specified in S16.3.3.1.2. If, at any step...

(b) for 100 percent bench seats: Retain seat location as determined for the driver.

5.7 Impact Configuration for Offset Deformable Barrier Test

It is apparent from the proposal in the SNPRM that the offset deformable barrier test was intended to be conducted on the driver's side of the vehicle. This is expressly described in S18.1 of the regulatory text, which requires " impacting only the driver side of the vehicle." This does not, however, necessarily imply that this is the left side of the vehicle. DaimlerChrysler produces some limited number of vehicles that are used as delivery vehicles that are right-hand drive vehicles (not limited to postal vehicles). To clarify the intention of this requirement, and to make the requirement consistent with S18.1, S18.2.4 must be modified as follows:

DaimlerChrysler petitions for the following modifications to the regulatory text:

S18.2.4 Impact configuration. ... The test vehicle shall be aligned so that the vehicle strikes the barrier with 40 percent overlap on the ~~left~~ driver side of the vehicle...

5.8 Positioning Requirements for Suppression Tests - Three-year-old Dummy

S22.2.2.4(b) specifies that the legs of the dummy, in a seated position, should be vertical. This requirement should only apply to the tibias of the dummy.

DaimlerChrysler petitions for the following modification to the regulatory text:

(b) Position the dummy in the seated position forward in the seat such that the ~~legs~~ tibias are vertical and rest against the front of the seat with the spine vertical. ...

In the above referenced section, and other static suppression test procedures, use of a thread to stabilize the position of the dummy is allowed. However, these sections (e.g., 22.2.2.3(b), 22.2.2.4(b), 22.2.2.5(d), and 22.2.2.6(d)) also require that the thread "not interfere with the operation of the air bag". Since these are tests of a suppression system and no air bag deployment is required by the test, this is an unnecessary requirement.[12]

> **DaimlerChrysler petitions for the following modification to the sections of the regulatory text referenced above:**
>
> **... To keep the dummy in position, a thread with a maximum breaking strength of 311 N (70 lb)** ~~that does not interfere with the air bag~~ **may be used to hold the dummy.**

5.9 ISO 1 Test Position for Six-year-old ATD, Low Risk Deployment

S24.4.2.2 states that the six-year-old test dummy must have its legs removed as part of the set-up procedure. This condition will change the center of gravity and moment of inertia characteristics of the dummy. Thus, the kinematics (and kinetics) may or may not be representative of a normally proportioned six-year-old human, and may affect the data measured by the dummy in the static deployment test. This operation should only be performed in those vehicles where proper positioning of the test dummy is not possible with the legs attached.

> **DiamlerChrysler petitions that S24.4.2.2 be modified to require the removal of the legs of the dummy only when necessary to position the dummy per the specified procedure.**

[12] In static low risk deployment tests, position 1 and 2, there are similar requirements that <u>are</u> necessary when an air bag is being deployed.

Studies of Neck Injury Criteria
Based On Existing Biomechanical Test Data

Abstract

This paper presents two analytical approaches to evaluate the N_{ij} injury criterion using previously published biomechanical data. A direct fit optimization analysis is applied to re-examine the intercepts used in the N_{ij} criterion. The results show that no values of the intercepts used in the N_{ij} criterion corresponding to compressive force, extension moment and flexion moment will optimally separate the injury and non-injury cases in the biomechanical data set. Only the tensile intercept allows identification of the injury risk. The tension and bending moment data in the same test series were examined for correlation with injury prediction using a variety of standard statistical techniques. All indications are that increasing the weight given to moment decreases the accuracy of the prediction. Moment is a confounding random variable in these biomechanical data sets. Only neck tension is shown as a reliable predictor of injury potential.

1. Introduction

Determining realistic biomechanical injury criteria for impact conditions is a formidable task. The results and conclusions from many studies are incomplete and potentially invalid. This is a consequence of the inability to validate the results, the multiple mechanisms for a given injury, the non-uniqueness of an injury for a given input as well as the complexity of human anatomy, material properties and structure. Only a limited number of tests can be conducted due to cost and complexity. Either postmortem-human or animal human surrogates must be used. In addition, there is never access to the real physical phenomena of an impact event. Tests are always idealized and are limited by experimental errors, assumptions and constraints. Finally, the tool used to estimate the parameters of human response, the anthropomorphic test device (dummy), may not represent the response of a living subject. Therefore, the results from any procedure used to determine assessment values, risk of injury or injury threshold might be distorted or potentially erroneous. However, the need remains for estimating human performance in impact. Efforts should be focused on improving or correcting current assessment values and threshold values.

The neck assessment values have recently been an active area of investigation. This is primarily the result of the re-examination of the live animal test data that was used to establish assessment values in the Federal Motor Vehicle Safety Standard (FMVSS) 208, the regulation for frontal crash occupant safety protection.

The human neck is a complex biomechanical structure that can sustain loading due to axial forces and bending moments acting on the spinal column. The mechanisms of injury are related to these loads. Automotive crash events impart time-varying loads on the human neck. Researchers have tried to characterize the injury potential of these complex loading conditions in the form of injury criteria. An injury criterion that combines the effects of tension and moment, N_{ij}, has been adopted in FMVSS 208. Current regulations governing the performance of occupant safety protection systems have generally been based on the research used to formulate the N_{ij} criterion.

The objective of the work is to determine if the existing criteria are rigorously supported by the test data as good indicators of neck injury risk. This paper presents two analyses that use the same biomechanical data that is the basis for N_{ij}. The first analysis is a direct fit optimization that re-examines the constants used in the N_{ij} criterion. The second analysis follows a statistical methodology and examines whether tensile force and extension bending moment make a significant contribution to the prediction of injury. The appropriateness of neck injury criteria that use combinations of tension and bending moment is assessed. This study also suggests what type of criterion the available test data support.

2. Background

Neck injury criteria are used to assess whether protection of the occupant's neck complies with a regulation. The neck injury criterion, like other injury criteria, is derived from a biomechanical test database using some type of data analysis methodology. Neck injury due to inertial load of the head while the torso is restrained by a seat belt or seat back has been the subject of some study. However, the biomechanical test database for the more complex loading condition resulting from air bag interaction consists primarily of a series of tests conducted to study the injury potential to an out-of-position occupant. Mertz, et. al. [1] and Prasad and Daniel [2] reported paired sets of matched tests conducted on piglets and a crash dummy representing three-year old children. Small pigs were chosen to represent the size, weight and state of tissue development of three-year-old children. The same conditions (speed, air bag type and subject position) were used on both the piglet and the dummy.

Broad ranges of test conditions were involved, resulting in a spectrum of injuries to different body regions of the piglets. The level of injury resulting from this particular condition is determined by necropsy of the animal and the mechanical response of acceleration and forces recorded by the dummy. Analysis of the test data is given in [1-2]. Further analyses are given by Mertz and Weber [3] and Mertz, Prasad and Irwin [4].

Mertz and Weber examined the relationship between neck injury level and the peak neck tension force. With a statistical procedure, a neck injury risk curve was established, which shows the percentage of porcine subjects with significant neck injuries as a function of the peak neck tension. The results showed that with a peak tension force of about 1050 N to 1350 N, the risk of injury increases from near zero to near 100%.

Prasad and Daniel [2] analyzed the dependence of neck injury severity on the loading represented by three different measures: peak neck tensile force, peak neck extensional moment and a specific combination of the two. Their test data, which were derived from the same test setup and procedure as the Mertz and Weber tests, indicated that all piglets sustained significant neck injuries for peak tensile forces above 1925 N. When the dependence of the injury on the peak extensional moment was examined, the authors suggested that injury severity depended on a combination of tensile force and moment. The injury was assumed to depend linearly on combined peaks of tensile force and extensional moment at a given time. It was concluded that a straight line, passing through the tensile force axis at 2000 N, and the extensional moment at 34 Nm, appears to delineate the no neck injury zone and the severe injury zone.

Mertz, Prasad and Irwin [4] combined and analyzed the data reported in [1] and [2] using the statistical method reported in [3]. The results of this analysis for tension alone create a one percent risk of AIS $\geq$ 3 injury at 1070 N. When the peak extensional moment alone is considered, 13.0 Nm corresponds to the same injury risk. The injury is related directly to the peak value of a specific combination of the force and moment, N_{TE}, which uses a simple cross-neck force distribution model:

$$N_{TE} = f\,(M_E + \frac{D}{2} F_T) \quad (1)$$

where M_E and F_T are the extensional moment and tensile force as functions of time, D is a constant related to the geometry of the neck and f is a constant that is determined from injury and force and moment data. Based on the test data in [1] and [2], the coefficient f can be determined. This results in the following:

$$N_{TE} = \frac{M_E}{M_C} + \frac{F_T}{F_C} \quad (1')$$

where M_c is 20.0 Nm and F_c is 1590 N for 3-year olds.

Neck injury assessment values first became part the FMVSS 208 regulation in 1997. Individual limits are given for forces and moments of the 50th percentile adult male dummy neck during a sled test. A new neck injury criterion, N_{ij}, was introduced in September 1998 in a Notice of Proposed Rulemaking (NPRM) for FMVSS 208 [5]. N_{ij} is defined as:

$$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}} \quad (2)$$

where F_z and M_y are the axial force and the neck flexion-extension moment as functions of time. F_{zc} and M_{yc} are normalization constants. A value F_{zc} is given when F_z is tensile force and a possibly different F_{zc} value is used when F_z is a compressive force. Similarly, two values are used for M_{yc} depending on whether M_y is extension or flexion. F_{zc} and M_{yc} values are dependent on the representative gender and age of the dummies (partly based on the biomechanical data reported in [1-4]). These values were modified in a

Supplemental Notice of Proposed Rulemaking (SNPRM) for FMVSS 208 in 1999 [6]. They were further revised in 2000 in the FMVSS 208 Final Rule [7]. In this regulation, the values of F_{zc} and M_{yc} for the 3-year old child dummy are as follows:

F_{zc} = 2120 N when F_z is in tension,
F_{zc} = 2120 N when F_z is in compression,
M_{yc} = 68 Nm when M_y is flexion and
M_{yc} = 27 Nm when M_y is in extension.

Four values of N_{ij} are computed as functions of time. The four values correspond to the possible combinations of axial force and moment: tension-extension, tension-flexion, compression-extension and compression-flexion. In addition to limiting any of the N_{ij} values to 1.0, the regulation further requires that the peak tension force shall not exceed 1130 N and the peak compression force shall not exceed 1380 N at any time for the 3-year old child dummy. F_{zc} and M_{yc} values for dummies of other sizes are also given and they are essentially arrived at by scaling the above numbers.

The regulatory requirements for the 3-year old dummy can be depicted in M_y - F_z space as shown in Figure 1. The N_{ij} requirement is represented as a diamond shape. In this depiction, the values for M_{yc} and F_{zc} correspond to the intercepts of the N_{ij} limit lines on the axes. The peak tension and compression limits appear as vertical lines.

3. Existing Biomechanical Data Used in Analysis

Out of the forty-six tests (forty-three piglet plus three baboon tests) reported in [1], data of thirty-three tests were obtained for this study. Twelve tests out of the fifteen reported in [2] were also obtained. Therefore, forty-five paired piglet-dummy tests were used in this study. No distinction is made between those from [1] and those from [2] because the test methodology and setup were such that the tests can be considered as a single test program.

Necropsies of the pigs allowed injury severities to be correlated with corresponding measurements made on the test dummy. The dummy neck force and moment time histories and the corresponding piglet neck injury level data from a subset of the tests that are reported in [1-2] were obtained from their respective original sources [8,9] for this study.

Only the part of the time histories that are considered relevant to the air bag loading should be used for the analysis. Efforts were made to assure that the selection of the time duration was consistent with that used in [1-4].

4. Direct Fit Analysis of the N_{ij} Criterion

This analysis assumes that neck injury is governed by the N_{ij} as defined in Equation (2) where F_{zc} has unique values for tension and compression and M_{yc} has unique values for flexion and extension. The objective is to use the existing test data described above to determine four intercept values that allow a best discrimination between injury and non-injury cases. Because of the nature of the tests and types of injuries observed in the subjects, flexion and compression should not be explainable values and should be not related to injury. They are included as a test of the procedure. If the procedure is valid, there should not be a value for the flexion and compression intercept that offers a clear advantage in injury prediction.

This approach seeks to minimize, with respect to $\overline{L}$ (a vector of all four to-be-determined intercepts), a fit measure p that allows the "best" separation of injury and non-injury tests, per some requirement (a similar method is presented in [10]). Figures 2a and 2b show the time histories of the tests in the tension-moment space along with the diamond-shaped failure envelope corresponding to N_{ij} = 1.

The fit measure p is defined as:

$$p(\overline{L}) = \left(\sum_{i=1}^{45} (a_i(cI_i, I_i)\, cI_i - I_i)^2\right)^{1/2} \qquad (3)$$

where cI_i is a "converted" injury classification for the ith test based on the N_{ij} value: cI_i = 1 ("serious-to-fatal injury"), if $N_{ij} \geq 1$ and $cI_i = 0$ ("no-to-low injury") if $N_{ij} < 1$. I_i is the injury classification from the ith test result: $I_i = 1$ if $AIS_i \geq 2.5$ and $I_i = 0$ if $AIS_i < 2.5$. a_i is a weighting factor given to the ith test that allows the fit to be carried out for different requirements.

The similarity between the N_{ij} criterion and the tension-extension based criterion reported in [4] is apparent. Further, the determination of the values of M_c and F_c in [4] and the determination of the intercepts through the fit analysis in this study appear to be similar. However, two differences are worth noting here. Most importantly, in [4], there is a preset relationship between Mc and Fc, as given by Equations (1) and (1'), which is a result of a simple cross-neck force distribution model assumption. Secondly, only the tension and extension intercepts are considered as in [4]. In this study, all of the intercepts (tension and extension as well as compression and flexion) are considered.

Two different fit requirements were examined:

(1) $a_i = 1$. The same weight is given to all cases; therefore, the final fit given by minimizing p is one that makes the minimal number of "incorrect" predictions of injury by the N_{ij} criterion.

(2) $a_i = w$, if $cI_i = 0$ and $I_i = 1$; else $a_i = 1$. The weighting factor, w, is a large number given as a penalty to the case where the actual test is an injury condition, but the N_{ij}

predicts non-injury. The incorrect prediction of an actual injury case is penalized more than the incorrect prediction of an actual non-injury case. Therefore, the final fit given by minimizing p is one that predicts all actual injury cases correctly and, at the same time, makes the minimal number of incorrect predictions about the actual non-injury cases with a suitably selected value of w (in this study, w = 25 was used).

The direct fit analysis was applied to both the case where all four intercepts were allowed to vary and the case where only the tension-extension intercepts were allowed to vary. The latter case assumes that the observed injury was all from this mode of loading.

The requirement for a minimal number of incorrect predictions (i.e., the fit when $a_i = 1$) was considered with all four intercepts allowed to vary. The response of p is represented by the mesh response surface in Figure 3. The response surface is largely a cylindrical surface after the extension moment intercept exceeds about -70 Nm – indicating that only one variable, tension, affects the injury predominantly. There is a value for the tension intercept, approximately 1225 N, which minimizes the number of incorrect predictions. The limits for compression, extension and flexion do not appear to significantly affect the minimization of incorrect injury predictions. Figures 4b, 4c and 4d show that the fit measure, p, cannot be minimized by selecting any value of the extension, compression or flexion limits in the range of the existing data. The fit measure is not effected by increasing or decreasing the extension, compression or flexion limits beyond some value in the range of the available data. This suggests that fixing these parameters to a specific value will not contribute to accurately predicting injury in the range of available test data.

The requirement for a minimal number of incorrect predictions was also considered with only the tension and extension intercepts allowed to vary and only the tension and extension parts of the data are used. The response of p to different values of the two limits is given in the mesh response surface shown in Figure 5. The response is very similar to the four-parameter case. The fit measure, p, is minimized by a single value of the tension intercept. Specifically, the tension intercept is clearly defined, while the extension intercept does not affect the quality of the fit once it is beyond a certain value. Figure 6 shows that p cannot be minimized by selecting any value of the extension in the range of the existing data.

In both the four-parameter and two-parameter cases, the tension limit is the only parameter that effectively minimizes the number of incorrect predictions of injury. The range of the existing data does not appear to support the use of compression, extension or flexion in attempting to accurately predict injury.

The same type of investigation was conducted for the case where minimizing requires predicting all actual injury cases correctly and making the minimal number of incorrect predictions about the actual non-injury cases (i.e., the fit when $a_i = w$). The results are shown for the four-intercept case in Figure 7. There is a value for the tension intercept (again, approximately 1225 N) which minimizes the fit measure.

This requirement was also examined for the two-intercept case. The results are shown in Figure 8. There is a value for the tension limit that minimizes the fit measure (approximately 1160 N). No value of extension in the range of available test data minimizes the fit measure. There is a small difference between the intercept values for tension obtained in the four-intercept and two-intercept cases. This is due to the trajectories of some no-to-low injury time histories passing through the tension-flexion quadrant as well as differences in step sizes in the search process.

Table 1. Summary of Intercept Values

	Tension Intercept	Extension Intercept	Compression Intercept	Flexion Intercept
Four Intercepts	1225 ± 25 N	≤ -70 ± 10 Nm	≤ -1600 N	≥ 280 Nm
Two Intercepts	1159 ± 9 N	≤ -88 ± 2 Nm	N/A	N/A

Table 1 summarizes the optimal intercept values found by the direct fit optimization method. The "±" symbol indicates the step size in calculating the response, and therefore, the uncertainty in the value. The "≤" and "≥" means the response (i.e., the prediction of the N_{ij} with these intercepts of the test results) remains the same below or above this value. The minimum value of the fit measure is not influenced by extension, compression and flexion in the range of available data. Insensitivity of the prediction to the intercept values is exhibited, except in the case of tension.

It is noted that the optimal points for the four-intercept cases for these two requirements (both minimizing the number of incorrect predictions and prohibiting incorrect actual injury prediction with fewest incorrect non-injury predictions) are identical. The same is true for the two-intercept cases for both requirements. This can only be true when the incorrect predictions for the first type of requirement are all about the non-injury test cases. When the actual test results and the predictions for the four-intercept and two-intercept cases are compared, the same 3 of 45 tests are miss-classified. The use of the four intercepts does not improve the predictions of injury with this particular set of test data.

5. Statistical Analysis of Tension and Moment

The results of the direct fit analysis calls into question whether the use of moment in a neck injury criterion contributes to the accuracy of injury prediction for air bag loading. To investigate further, two different analyses, principal component and confidence tests on the mean, were performed to investigate the predictive value of tension and extension moment. The direct fit analysis indicated that tension was the significant variable. For this reason, tension alone was considered. The focus was on determining whether extension moment makes a significant contribution to predicting a neck injury beyond what is seen with tension. The statistical analysis presented here shows that there is evidence to conclude that moment cannot provide additional separation between injury and non-injury in the experimental data set beyond the separation already achieved by the tension alone. The same data used in the direct fit optimization study was used in these analyses. The global peak values of tension and moment were used in this analysis as compared to the global peak values used in the calculation of N_{ij}. The individual variables will exhibit a stronger influence on injury using this approach. If moment is not found to be significant when its global peak is considered, it is unlikely to be a significant contributor to injury when it is applied in the N_{ij} criterion.

a. Principal Component Analysis

Principal component analysis seeks to maximize the variance of a linear combination of the variables under consideration (the peak values of tension (T) and moment (M)). The Abbreviated Injury Scale (AIS) values (i.e., designation of serious-to-fatal or no-to-low injury) will not be used in this analysis. All samples are combined together and no grouping of observations are assumed. The principal component analysis is concerned only with explaining the variance-covariance structure of the tension and moment variables through a linear combination of that has maximal variance. Seeking a linear combination with maximal variance is essentially searching for a line that the observations can be projected onto that creates the largest separation among the observations.

The first principal component is given by [12]:

$$P_1 = 1.000(T - E(T)) + 0.005(M - E(M)) \quad (4)$$

where E(T) and E(M) are the expected or mean values of the tension and moment where T is measured in Newtons and M is measured in Newton-meters. The relative sizes of the coefficients of tension and moment suggest that tension contributes significantly more to the determination of P_1. The test data do not show significant separation in terms of moment. However, tension, taken essentially alone, separates the data as widely as possible. This suggests the possibility that if the data is grouped into serious-to-fatal injury and no-to-low injury categories. Tension may be used to discriminate between the two categories.

The correlation between the first principal component and the two variables was also examined. The correlation values were found to be:

$$Corr\,(P_1,T) = 1.000 \text{ and } Corr\,(P_1,M) = 0.004$$

The first principal component is perfectly correlated with tension and, for all practical purposes, not correlated with moment. This implies that tension determines the value of the principal component and, hence, the scatter that exists in the data. The first principal component explains 99 % of the total variance. Therefore, P_1 can “replace” the original variables without practical loss of information.

The principal component analysis provides evidence to conclude that tension is the most important variable in this data set while moment appears to not be significantly informative. The results suggest that the principal component essentially duplicates the tension variable. Tension alone is able to explain 99% of the total information contained in the data. Thus, the principal component analysis gives evidence to suggest that moment can be omitted from the analysis without loss of information.

b. Tests on Mean Values

Tests were also conducted on whether the means values of tension and moment could be used to separate the data into serious-to-fatal injury and no-to-low injury categories. In this analysis, the AIS variables were used to categorize all the available observations into Group 1 (serious-to-fatal injury) and Group 0 (no-to-low injury). Group 1 is the family of all observations where AIS ≥ 3. Group 0 is the family of all observations where AIS < 3. This test examines whether tension (T) and moment (M) can be used to separate the data into the two groups.

The observed values, T and M, differ to some extent from one group to the other. If the observed values were not very different for subjects in Group 1 and Group 0, the two groups would be indistinguishable with respect to these variables. A multivariate test was done to investigate if these two variables were able to separate the two groups. In particular, a multivariate two-sample T^2-test was performed to determine if the mean value for Group 0, ($E(T_0)$,$E(M_0)$), was significantly different from the mean value for Group 1, ($E(T_1)$,$E(M_1)$).

The T^2-test examines whether the mean values of the tension and moment are equal for the two groups. The alternatives are:

$$H_0 : \overline{m}_0 = \overline{m}_1 \quad \text{vs} \quad H_a : \overline{m}_0 \neq \overline{m}_1 \tag{5}$$

Where $\overline{m}_i$ is the vector-valued expectation of the tension and moment for Group i = 0,1. The hypothesis test resulted in a p-value of 0.0001. Thus, there is evidence to conclude that the mean value of the vector (T, M) is significantly different for the two groups.

While this type of test is not strongly affected by lack of normality, a transformation of the variables T and M was applied to make the joint distribution of the transformed variables approximately normal. The Box-Cox [11] method was followed to transform the variables such that:

$$(\tilde{T}, \tilde{M}) = \left(1/\sqrt{T} \ , \ 1/\sqrt{M} \right) \tag{6}$$

The assumption of normality was reasonable and the T^2-test was performed using $(\tilde{T}, \tilde{M})$. The analysis of the transformed data supported the same conclusion reached above with the same significance level.

A test of the hypothesis that the moment data is redundant was also conducted. The data consists of a random sample (T_{0j}, M_{0j}) with j = 1,…,20 (Group 0) that is assumed to be distributed $N_2(\overline{m}_0, \Sigma_0)$ and a second random sample (T_{1j}, M_{1j}) with j = 1,…,25 (Group 1) that is assumed to be distributed $N_2(\overline{m}_1, \Sigma_1)$. A further assumption is made that the two samples are independent. The T^2-statistic based on the full set of variables (both T and M) is given by:

$$T^2 = (\overline{y}_0 - \overline{y}_1)' \left(\left(\frac{1}{n_1} + \frac{1}{n_0} \right) S_{pl} \right)^{-1} (\overline{y}_0 - \overline{y}_1) \tag{7}$$

where S_{pl} is the pooled covariance matrix and $\overline{y_i} = \left(\sum_j \frac{T_{ij}}{n_i} \quad \sum_j \frac{M_{ij}}{n_i} \right)'$.

The T^2-statistic based on the reduced set of variables (only M) is given by:

$$T_1^2 = \frac{20 \cdot 25}{45 s_M^2} \left(\sum_j \frac{M_{0j}}{20} - \sum_j \frac{M_{1j}}{25} \right)^2$$

The hypothesis of M redundant is rejected at level α if:

$$F = 41 \left(\frac{T^2 - T_1^2}{43 + T_1^2} \right) \geq F_{(a, 1, 41)}$$

For the combined data set, the value of the *F*-statistic above is 4.345, with a p-value equal to 0.045, implying that there is evidence to accept the hypothesis of M being redundant. This "additional information" test suggests that the moment data does not add significant information for purposes of separating the serious-to-fatal and no-to-low injury groups. This conclusion leads us to ask if moment has any power to distinguish between the two groups.

Univariate tests were also done to compare the mean moment value for the two groups. A test was done to determine if the mean value of the moment is equal for the two groups. The alternatives are:

$$H_0 : E(M)_0 = E(M)_1 \quad \text{vs} \quad H_a : E(M)_0 \neq E(M)_1$$

Where $E(\mathrm{M})_i$, is the expected value of the moment for Group i = 0,1. The necessary assumptions for this type of test (observations are independent, observations for each group are a sample from a population with a normal distribution and variances for the two independent groups are equal) seem to be reasonable. A univariate t-test to compare the two groups mean moment resulted in a p-value of 0.016. Thus, there is evidence to conclude that the mean moment for the two groups is not significantly different at level 0.01. The mean value of the moment can not be confidently used to separate the serious-to-fatal injury and no-to-low injury groups.

Finally, a univariate test to compare the mean tension value for the two groups was performed. As was done with moment, a test was done to determine whether the average value for the tension is equal for the two groups. The tension data is not likely to be normal (the distribution of Group 0 is skewed). Therefore, a Wilcoxon Rank Sum was used to compare the mean of the two groups. This test provides a non-parametric analog to the t-test used in the analysis of the mean moment. The only assumption is that the observations are independent. The p-value for this test is 0.0001. Thus, there is strong evidence to conclude that the average value of the tension for the two groups is significantly different. Tension can be applied to distinguish the injury and non-injury groups.

Figure 9, a scatter plot of the tension and moment data with the injury and non-injury cases indicated by legend, illustrates this point. The location of the means of the two groups is shown. The two means are significantly separated by tension. By contrast, the separation is not significant in terms of moment.

The additional information test gives evidence to conclude that the moment variable does not contribute anything significant beyond the information already available in tension for separating the serious-to-fatal injury and no-to-low injury groups. The univariate test conducted on moment reinforced this conclusion. The mean value of the moment is not significantly different for the two groups (the two mean moment values were not significantly different at 0.01 level). However, the mean value of the tension is significantly different for the two groups (the probability of observing a larger difference by chance alone is 0.0001)

There is confidence to conclude that, for all practical purposes, tension is the only valid variable. Moment is not informative in distinguishing between the serious-to-fatal injury and no-to-low injury groups. Therefore, if a linear combination of tension and moment is used to discriminate the two groups, the more weight given to moment will result in less power to discriminate the two groups. This conclusion can be supported more formally by trying to form a linear discriminant to classify observations of tension and moment into the two groups.

6. Classification Analysis: Allocation of Observations to Groups

In classification analysis a sampling subject whose membership is unknown is assigned to a group based on the parameter values associated with the subject. As in the previous statistical analysis of the observed measurements, all the available observations have been divided in two groups: Group 0 (no-to-low injury) and Group 1 (serious-to-fatal injury).

Three parameters were compared in their ability to classify the samples. Two separate approaches to linearly combining moment and tension were considered, N_{ij} and K [4] as well as tension (T) alone. K is an instantaneous peak kernel of moment and tension defined as:

$$K = M_E + cF_T \tag{8}$$

where c is a constant dependent on scale factors and characteristic dimensions of the neck (see Equation 1 as well). Fisher's discriminant function [12] was used to compare the performance of K, N_{ij} and T in classifying the samples. This technique transforms samples into a univariate space where the observations can be separated as much as possible. The discriminant function defines a threshold value in the univariate space that segregates the data into the separated groups. In this univariate case, the discriminant was only used to define a threshold.

The results of the classification procedure using Fisher's discriminant function for each of the parameters are summarized in Table 2. Each parameter was used to assign the samples to a group.

Table 2. Classifications Using Various Neck Injury Assessment Parameters

Parameter	Subject Group	Total Observations	Correct Classifications	Incorrect Classifications	Classification Rate
K	0	25	22	3	88%
	1	20	14	6	70%
N_{ij}	0	25	20	5	80%
	1	20	13	7	65%
T	0	25	22	3	88%
	1	20	16	4	80%

When the entire subject group is evaluated using the discriminant function, the largest percent correctly classified were observed when using tension alone.

One important way for judging the performance of any classification procedure is to calculate its "error rate" or misclassification probability. An estimate of the misclassification probabilities can be obtained using the cross validation method [13] (sometimes referred as "hold –out" method). This approach does not depend on the parent population and, for moderately-sized sample (such as the one with this data set), it is nearly an unbiased estimate of the expected actual error rate, E(AER). In this data set, where the parent population is unknown, the cross validation method gives the best available estimate of the probability that a classification function (K, N_{ij} and T) will misclassify a future observation based on the present sample.

Estimates of the probability of correct classifications are summarized in Table 3.

Table 3. Estimates of Correct Injury Classifications Using Cross Validation

Classification Variable	T	K	N_{ij}
1 – E(AER)	84.4%	80.0%	73.3%

The highest probability of correct classification rate results from using the tension variable. This result confirms what was observed in the previous two analyses: tension is the most informative variable in classifying an observation as either low-to-no injury (Group 0) or serious-to-fatal injury (Group 1). The multivariate and univariate statistical analyses suggested that there is evidence that moment has no power in classifying the observations. As expected, inclusion of moment degraded the predictive value of the analysis. Thus, the two injury assessment values that combine moment and tension, K and N_{ij}, have less power than the tension alone. Moment is only acting as a confounding variable. The estimated risk of serious-to-fatal injury as a function of tension using the method described in [14] is illustrated in Figure 11.

7. Discussion

An analysis of the data collected in [1] and [2] calls into question the value of using moment, either on its own or in combination with tension, as an indicator of neck injury. This result may seem counterintuitive. The neck is bent under the action of air bag loading. Bending a prismatic bar with homogeneous material properties will result in tensile and compressive stresses on the component being bent. Bending stress should be a contributor to ligamentous tissue failure in a similar manner to axial stress. This concept is the basis for the K and N_{TE} (the tension-extension part of the N_{ij} injury criterion). However, a rigorous analysis of the data shows a linear addition of extension moment to the tension data degrades the accuracy of injury prediction. Furthermore, injuries observed in the animal subjects are only related to tension.

Air bag deployment tests represent a complex set of loading conditions on the neck. The paired tests were conducted with the tacit assumption that the test device and the animal surrogate respond similarly to the application of this complex loading condition. Differences between the test device and the animal subject may offer a reason why the observed moment does not correlate with injury. The constant stress hypothesis that underlies the K and N_{ij} criteria assumes that the neck behaves as a prismatic, homogeneous bar. A biologic specimen has features that challenge this assumption.

The Hybrid III dummy response corridors were developed using inertial loading of the head while the torso is restrained by a seat belt and a seat back. A deploying air bag loads the head directly, creating a different type of load condition on the neck. Finally, inertial loading of the head causes the neck to behave as a cantilever beam with a point load at the free end. In simple terms, the maximum moment occurs when the deformation is at a maximum and deformation rate is at a minimum. By contrast, large moments can be imparted to the neck by air bag loading when the deformation rate is very high -- as much as an order of magnitude larger than what would be observed in inertial loading due to impact. Strain rate sensitivities in the test device may be influencing the moments recorded during the tests.

The test device may not be biofidelic for purposes of air bag loading. This may call into question whether it is appropriate to assume that standard crash test dummies can be used for paired animal tests during air bag loading.

8. Conclusions

Two analytical approaches were used to examine if the existing neck injury criteria for air bag loading are rigorously supported by the animal test data as good indicators of neck injury risk. A direct fit optimization analysis re-examined the constants used in the N_{ij} criterion. The results showed that no values of the constants used in to the N_{ij} criterion corresponding to compressive force and flexion moment will optimally separate the serious-to-fatal injury and no-to-low injury cases in the biomechanical data set. This result is expected based on the experimental procedures employed in the original tests. It is expected that only the tensile and extension intercepts should allow optimal identification of the injury risk.

The tension and moment data were examined to assess their injury prediction value using variety of standard statistical techniques. Tension alone is the best predictor of injury. Although a combination tension and moment can be used, all indications are that increasing the weight given to moment decreases the accuracy of the prediction. Moment is a confounding random variable in the biomechanical data set.

Various neck injury criteria have been proposed which use tension and bending moment as separate variables and in linear combinations as predictors of injury for air bag loading. This investigation indicates that the use of moment is not supported by the biomechanical data used to form the basis for these proposed criteria. With the currently available test data and anthropomorphic test devices, only neck tension is a reliable predictor of injury potential.

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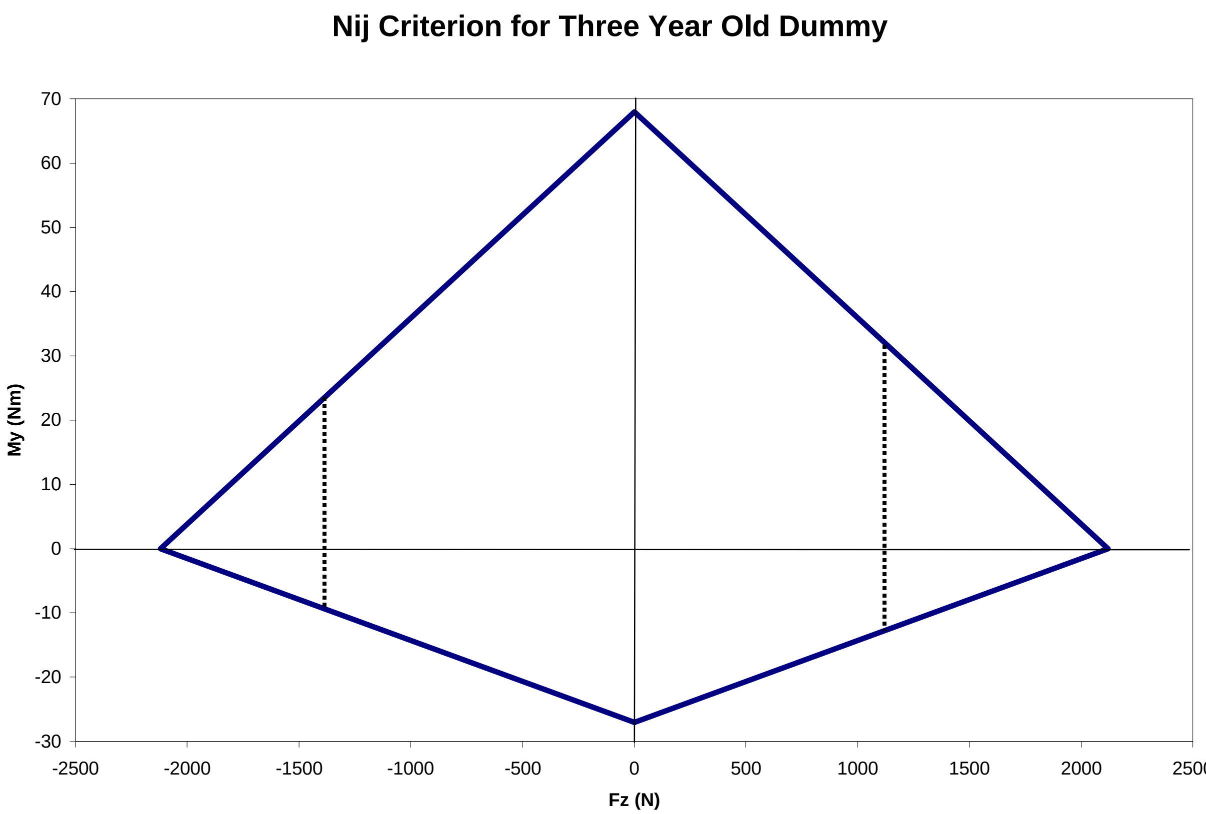

Figure 1. Neck Injury Protection Requirement Envelope of FMVSS208 Regulation for a 3-year-old Test Dummy.

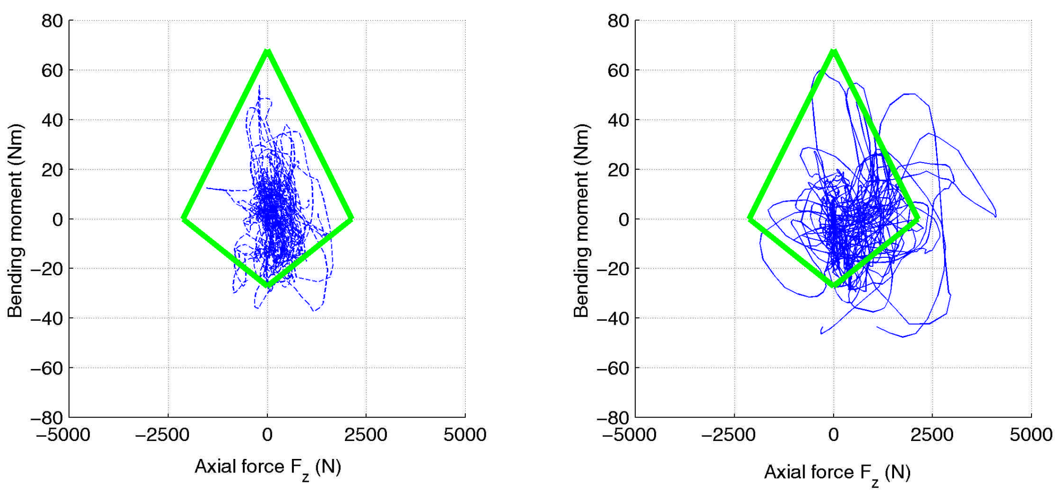

Figure 2. Time Histories of No-to-low Injury Cases (a) and the Serious-to-fatal Injury Cases (b).

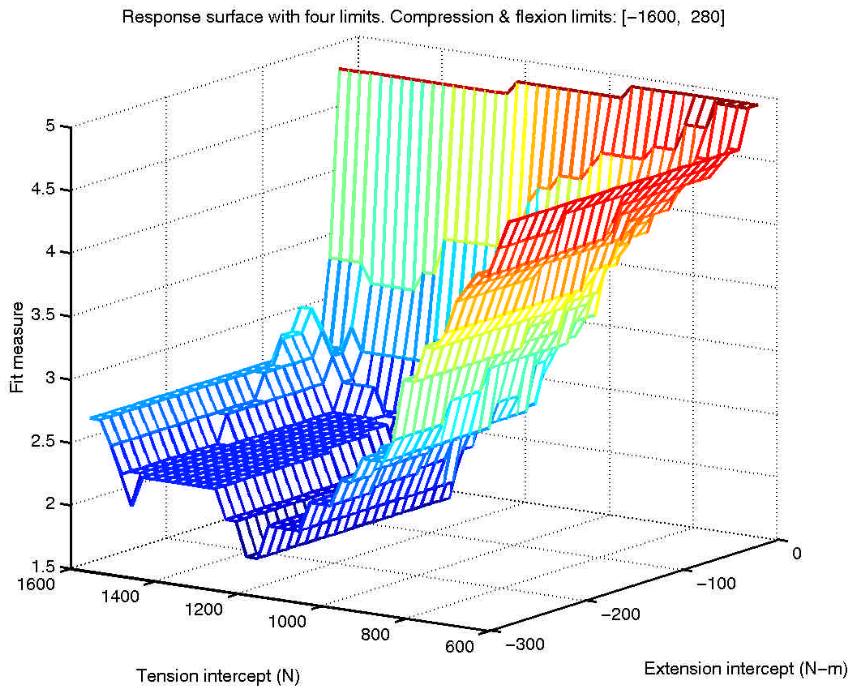

Figure 3. Response Surface of the Fit Measure with the First Requirement and Four Intercepts Allowed to Vary.

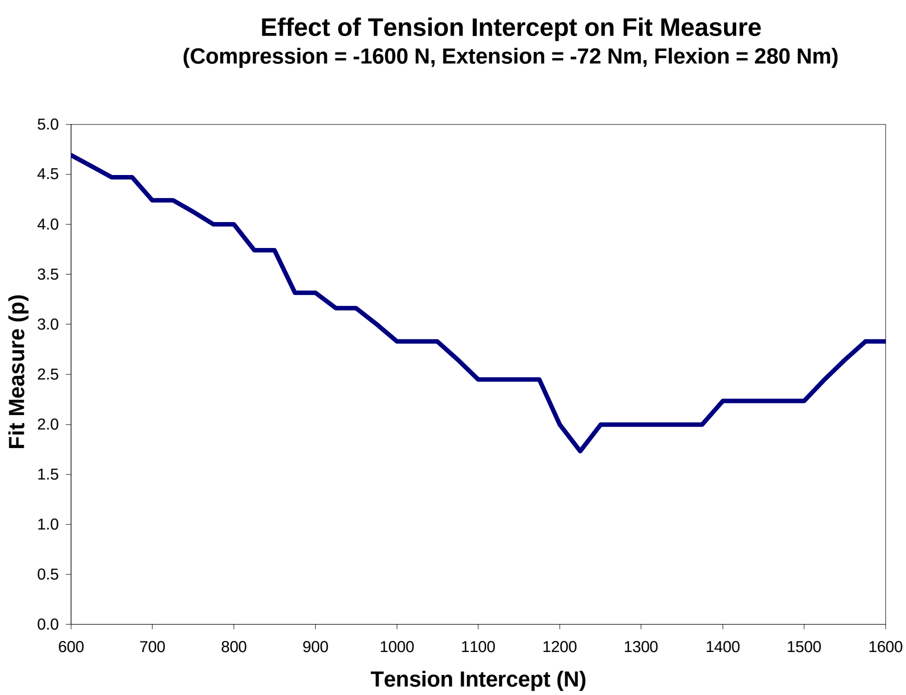

Figure 4a. Sensitivity of Fit Measure to the Tension Intercept With the First Requirement When Four Intercepts are Allowed to Vary.

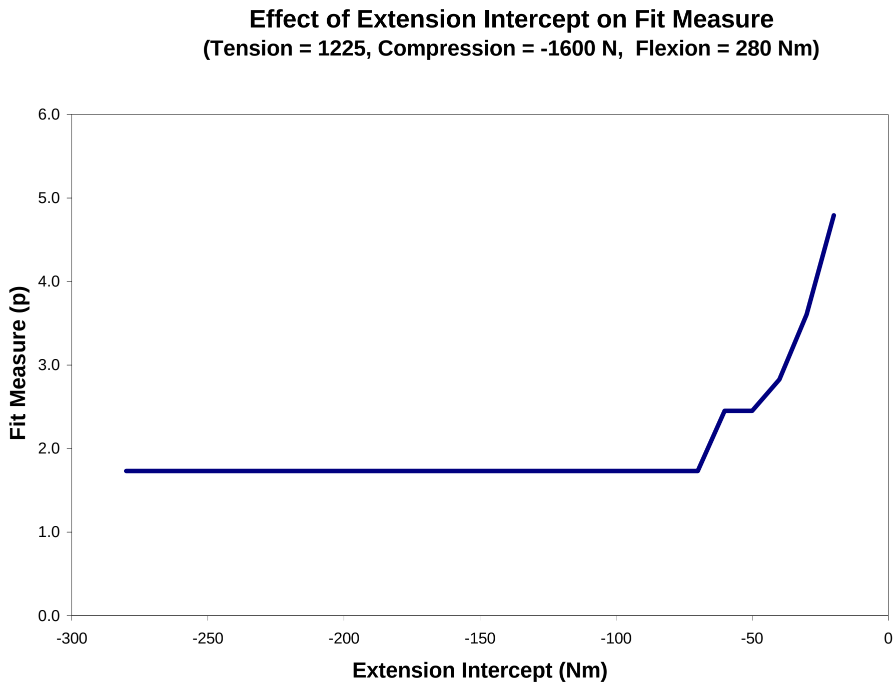

Figure 4b. Sensitivity of Fit Measure to the Extension Intercept With the First Requirement When Four Intercepts are Allowed to Vary.

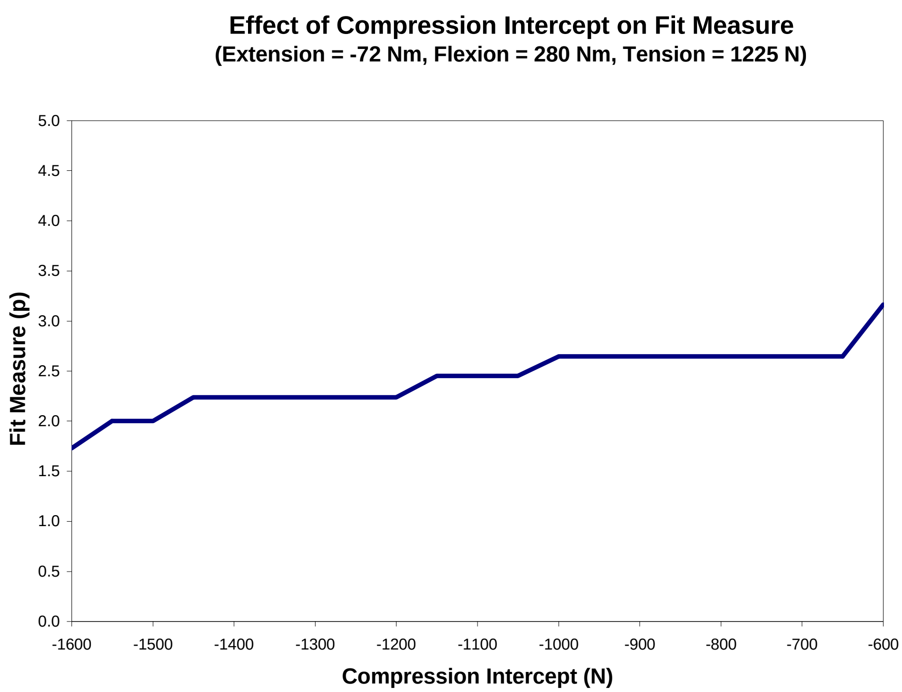

Figure 4c. Sensitivity of Fit Measure to the Compression Intercept With the First Requirement When Four Intercepts are Allowed to Vary.

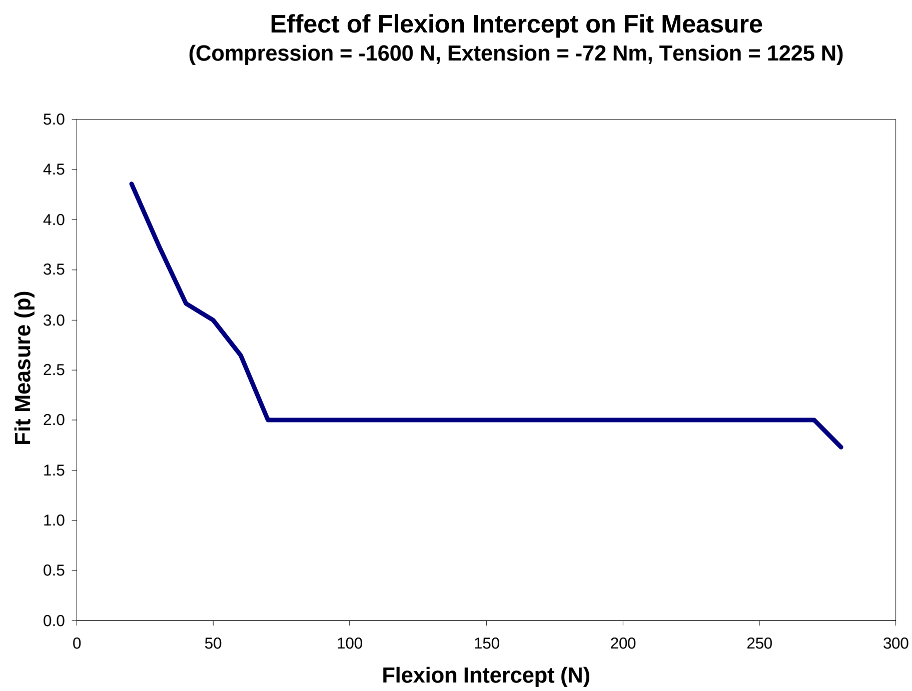

Figure 4d. Sensitivity of Fit Measure to the Flexion Intercept With the First Requirement When Four Intercepts are Allowed to Vary.

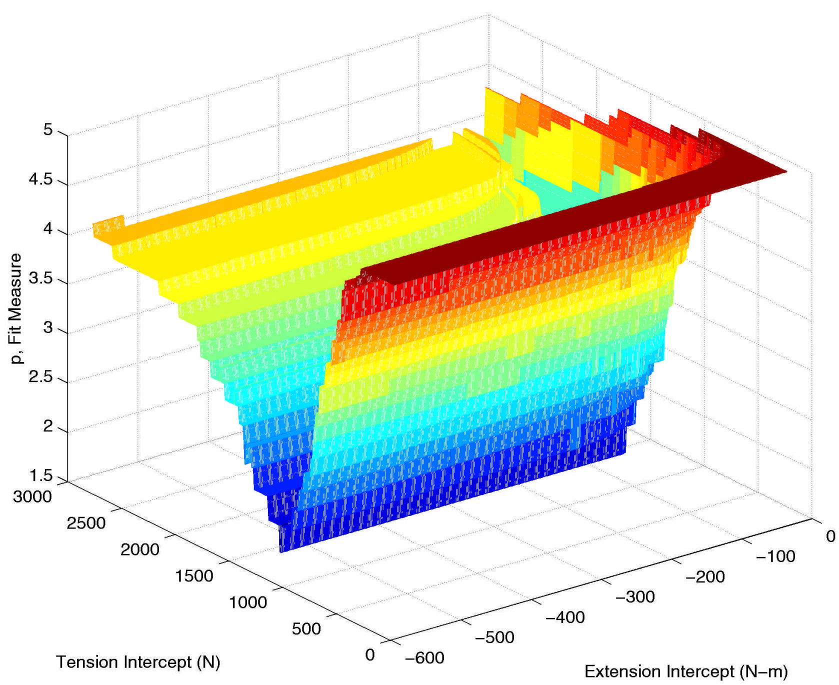

Figure 5. Response Surface of the Fit Measure with First Requirement and Two Intercepts Allowed to Vary.

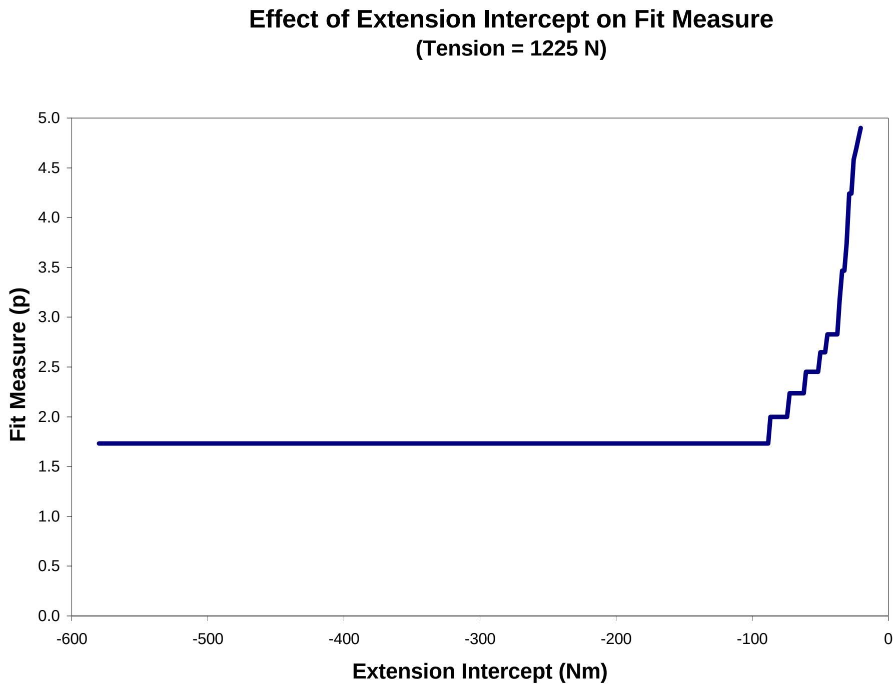

Figure 6. Sensitivity of Fit Measure to the Extension Intercept With the First Requirement When Two Intercepts are Allowed to Vary.

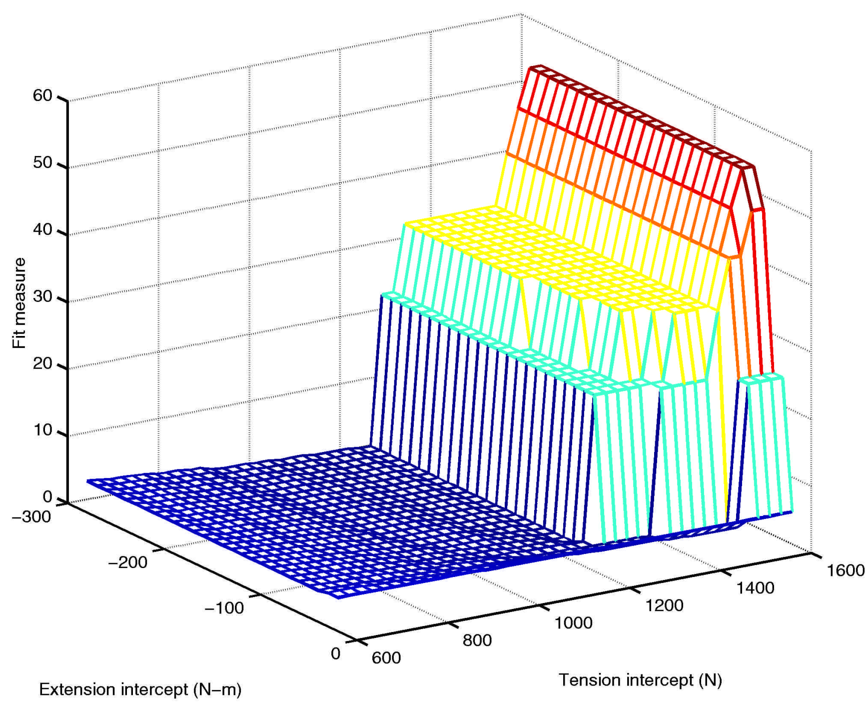

Figure 7. Response Surface of the Fit Measure With the Second Requirement and Four Intercepts Allowed to Vary.

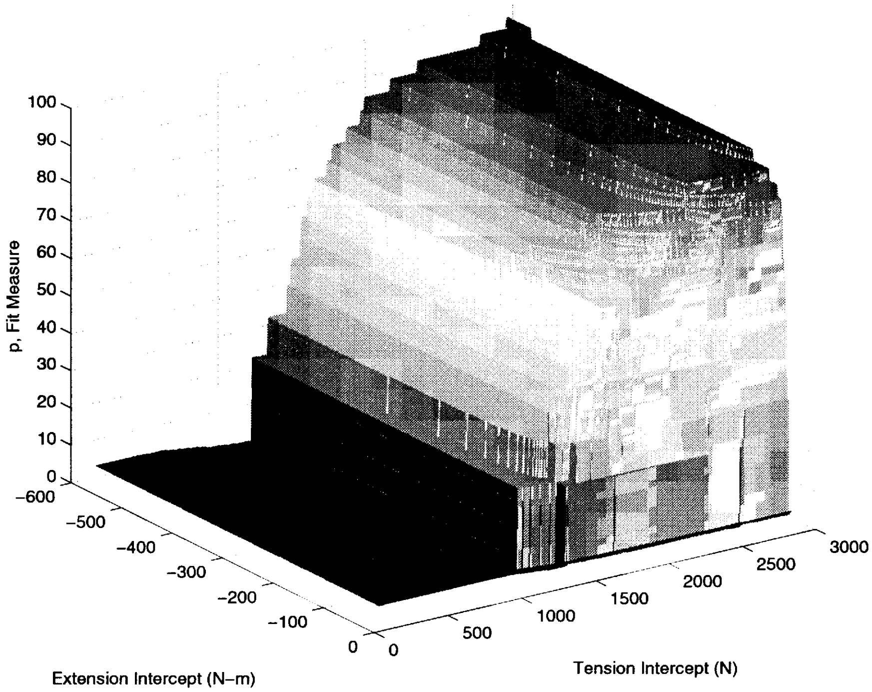

Figure 8. Response Surface of the Fit Measure With the Second Requirement and Two Intercepts Allowed to Vary.

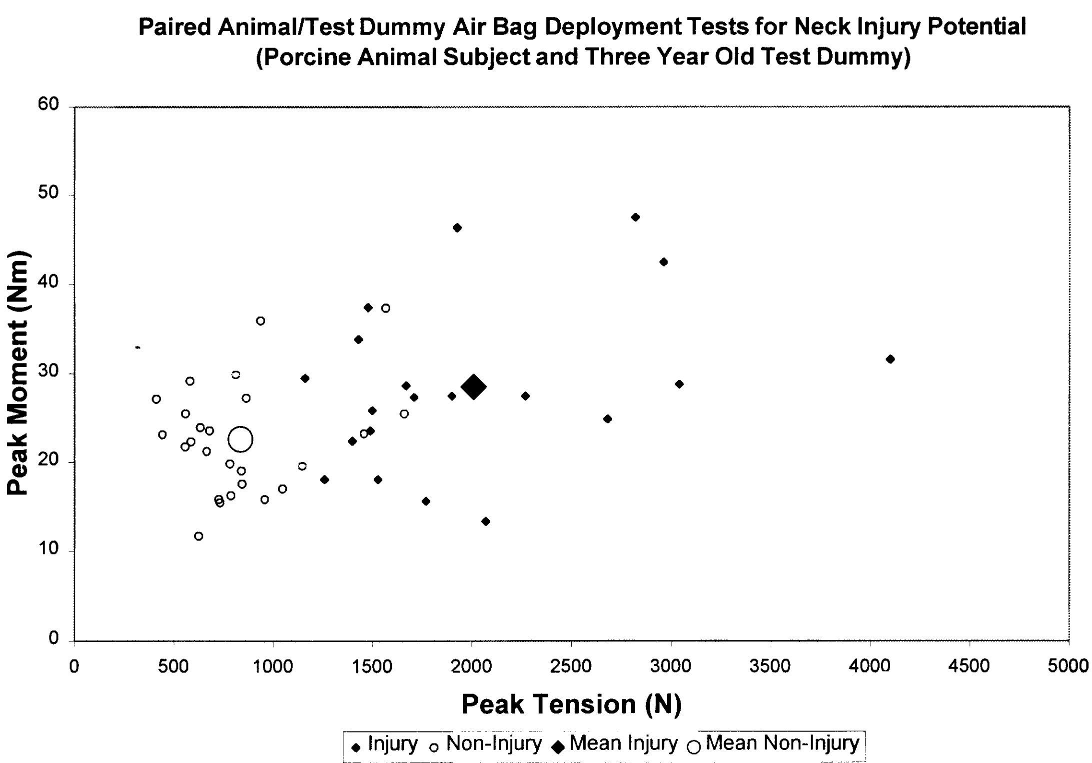

Figure 9. Scatter Plot of Biomechanical Moment and Tension Data.

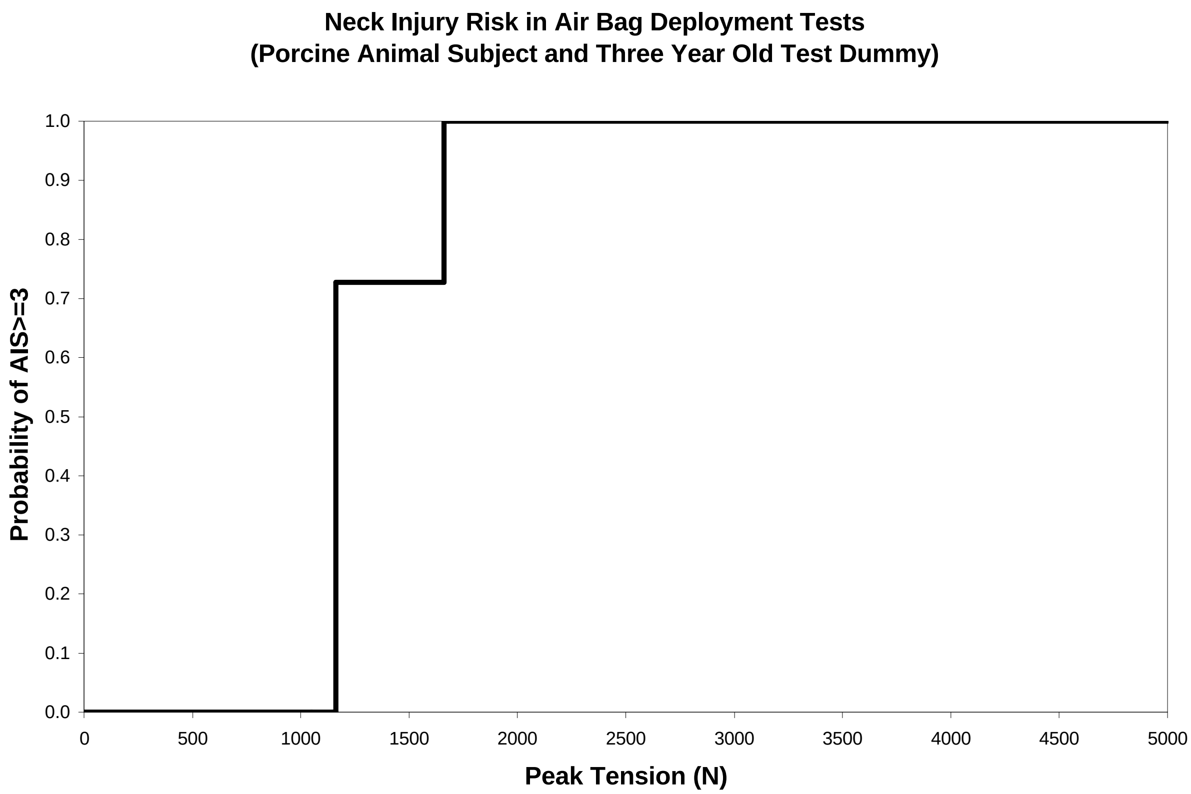

Figure 10. Estimated Risk of Serious-to-Fatal Injury Based on Tension Data.