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An Overview of Existing and Needed Neck Impact Injury Criteria for Sideward Facing Aircraft Seats

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ABSTRACT

This paper reviews some of the research studies conducted by both the aircraft and automobile communities that evaluated the potential for occupant injury where the vehicle's occupant(s) were exposed to lateral impact loads. The results of early and recent research studies that included human subject impact tests, sled impact tests, and full-scale vehicle impact tests are summarized. The applicability of those research studies with respect to the development of tolerance limits for lateral neck loading for inclusion in the performance standards for side facing aircraft seats is discussed. Proposed tolerance limits for neck lateral loading are presented along with a recommendation for future research in this area.

INTRODUCTION

Current performance standards for the certification of aircraft seats include both static and dynamic load assessments. The seat static strength standards establish a baseline performance level and provide a point of reference for the seat dynamic performance standards. The seat dynamic performance standards go beyond a strength assessment whereas they also quantitatively evaluate the potential for human impact injury that cannot be accomplished statically.

Sideward facing aircraft seats were not emphasized in the development of the seat dynamic performance standards and thus the occupant injury criteria found in those standards are more applicable for forward or aft facing seats. The recent proliferation of business jet aircraft and the widespread usage of sideward facing aircraft seats installed in those aircraft has revealed the deficiency in the occupant injury criteria found in the seat dynamic performance standards. Currently without applicable occupant injury criteria sideward facing aircraft seats cannot be certified to a level of safety consistent with that afforded by forward and aft facing seats. Thus sideward facing aircraft seats that have a dynamic test certification basis must be certified through an exemption process with special conditions. The Federal Aviation Administration (FAA) is ardently working with a number of research organizations to develop injury criteria that will be applicable for occupants of sideward facing aircraft seats in order that sideward facing seats might be certified to an equivalent level of safety.

Figure 1 - Example Business Jet Cabin Interior

AIRCRAFT SIDEWARD FACING SEAT RESEARCH STUDIES

CAMI/GESAC Study

An early study at the FAA's Civil Aeromedical Institute (CAMI) was initiated to investigate the potential for injury of sideward facing seat occupants (Ref. 1). That study interactively used full-scale seat/occupant impact tests and DYNAMAN simulations of those tests to evaluate a number of potential occupant injury parameters. A variety of single and multiple occupant seating configurations, some of which had seat end closures such as bulkhead surfaces or armrests, were evaluated. The results of the study showed fair to good agreement between the tests and the simulations for a number of load and injury parameters. It was noted that the only injury parameter that consistently exceeded the tolerance limit was the lateral neck moment. Figures 2 and 3 are examples of the results of a DYNAMAN simulation that illustrates occupant motion and shows a comparison of lateral neck loads.

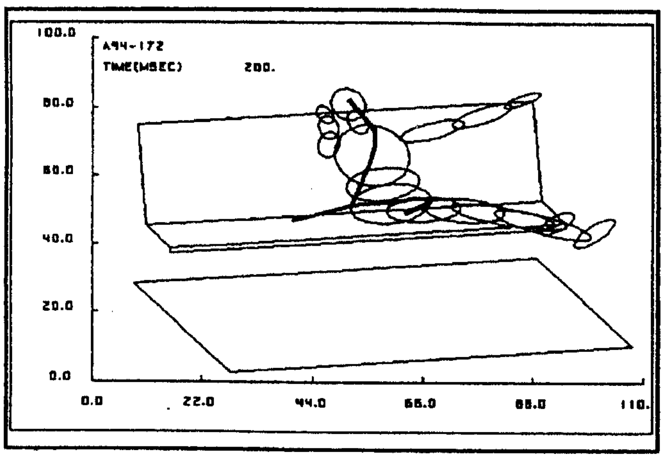

Figure 2 - DYNAMAN Occupant Computer Simulation @ T = 250 MS

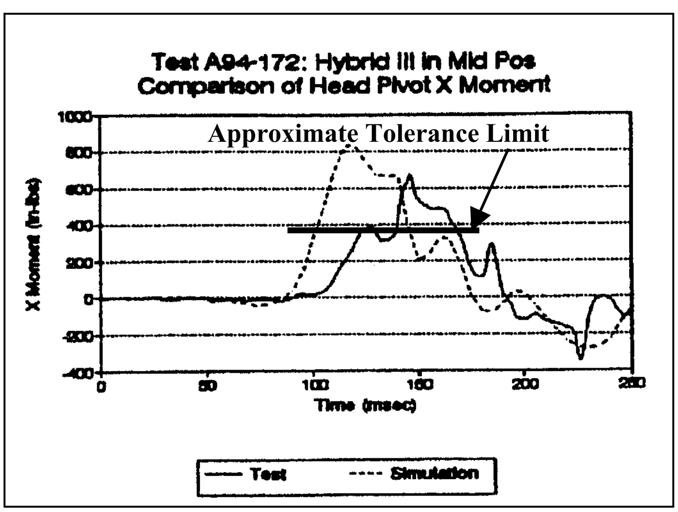

Figure 3 - Comparison of Lateral Neck Moments

Even though this early study did not establish tolerance limits for neck lateral loading applicable for sideward facing seat occupants it did provide a foundation for further research studies that were directed towards a more comprehensive evaluation of seat/occupant interaction and the potential for occupant injury.

<u>CAMI/NIAR Study</u>

Another cooperative study between CAMI and the National Institute for Aviation Research (NIAR) at the Wichita State University in conjunction with the Aircraft Design and Manufacturing Research Center (ADMRC) expanded on the initial CAMI/GESAC study (Ref. 2). Some of the objectives defined for the CAMI/NIAR study were:

- Investigate potential occupant injuries corresponding to single and multiple-occupant (divan-type) sideward facing seat configurations.
- Demonstrate an "equivalent level of safety" as compared to that on forward or aft-facing seats.
- Identify potential configuration(s) that provide the highest level of occupant protection.

The CAMI/NAIR study interactively used the results of seat/occupant computer models, full-scale seat dynamic tests, and parameter studies to assess a number of seat/occupant configurations in an attempt to establish a set of pass/fail injury criteria along with design guidelines and testing procedures. Figure 4 schematically depicts that approach.

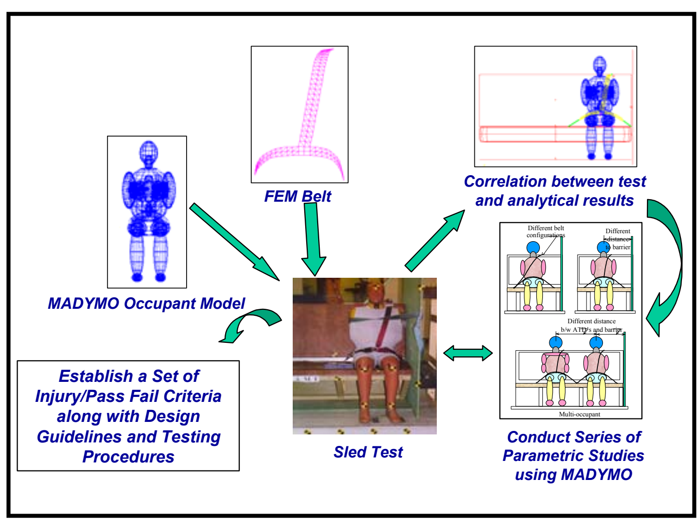

Figure 4 - CAMI/NIAR Methodology

The CAMI/NAIR study enhanced the understanding of the interaction of multiple occupants on sideward facing seats, provided a comprehensive evaluation of potential injury mechanisms and criteria, and defined a so called "body centered" occupant restraint system that may have the potential to minimize occupant motion and injury. However the objective of demonstrating an "equivalent level of safety" as compared to that on forward or aft-facing seats was not achieved. One of the conclusions of the CAMI/NIAR study was consistent with one of findings from the earlier CAMI/GESAC study. It was noted that the calculated Head Injury Criteria (HIC) and the measured neck lateral moments exceeded their injury thresholds. The conclusions also state that these potential injury mechanisms need to be addressed if an equivalent level of safety is sought.

While both the CAMI/GESAC and CAMI/NIAR studies provided much insight with respect to the performance of sideward facing seats and the definition of potential injury mechanisms for the occupants of those seats neither study established any proposed limits for lateral neck loading.

AUTOMOTIVE SAFETY RESEARCH REVIEW

Accident Injury Modes

Occupant injury modes, the impact environment, and the severity levels of automotive accidents were reviewed and compared to those of aircraft. It was thought that the means employed for occupant impact protection in automobiles might have application for aircraft accidents.

It was found that neck injury (other than whiplash) has not been a dominant occupant injury mode in automobile accidents. One automobile accident study found that in car-to-car side impacts neck injury is the most severe injury for a little more than 20% of the total head/neck region injuries (Ref. 3). However those neck injuries are not typically serious and account for approximately 8% of the total HARM (a measure of the cost to society) in the head body region as shown in Figure 5. Even though these neck injuries tend to be non-life threatening they are not to be dismissed for they can lead to long term pain. Head injury, specifically brain injury, accounts for more than 60% of the total HARM in the head body region. Consequently much of the automotive research directed towards occupant safety relates to occupant head injury protection and not to the prevention of neck injury.

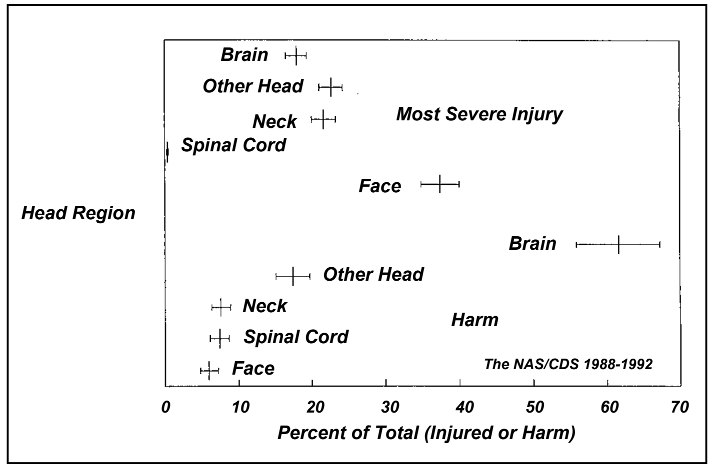

Figure 5 - Injury and Harm by Head Body Region in Automobile Side Impacts

Accident Severity Levels

There are a number of characteristics of the automobile and its impact environment that minimize the occurrence of serious neck injuries in automobile side impacts. For example the severity of an automobile side impact (G level and velocity change) is typically less than the 44 ft/sec impact condition found in 14 CFR Part 25, §25.562, the aircraft seat dynamic performance standards for transport category airplanes (Ref. 4). In comparison the above study (Ref. 3) has found that the maximum lateral "delta V" in automobile side impacts is less than 40 ft/sec as shown in Figure 6.

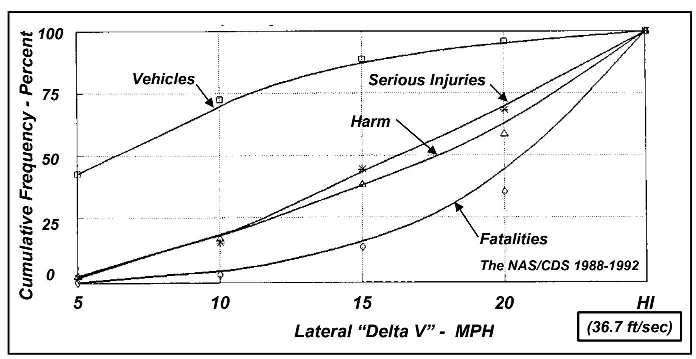

Figure 6 - Cumulative Frequency Distribution For Lateral "Delta V" in Side Impacts

The results of another automotive side impact accident study (Ref. 5) that are summarized in Figure 7 has found that a 35 km/hr (31.9 ft/sec) velocity change represents about an 80th percentile level for injury producing mechanisms. A 31.9 ft/sec lateral velocity change is typically used as a nominal "delta V" in automobile occupant safety research programs. That study like the previous shows that the automobile side impact accident and test environments, specifically the lateral velocity change "delta V", are less than the 44 ft/sec velocity change found in 14 CFR Part 25, §25.562.

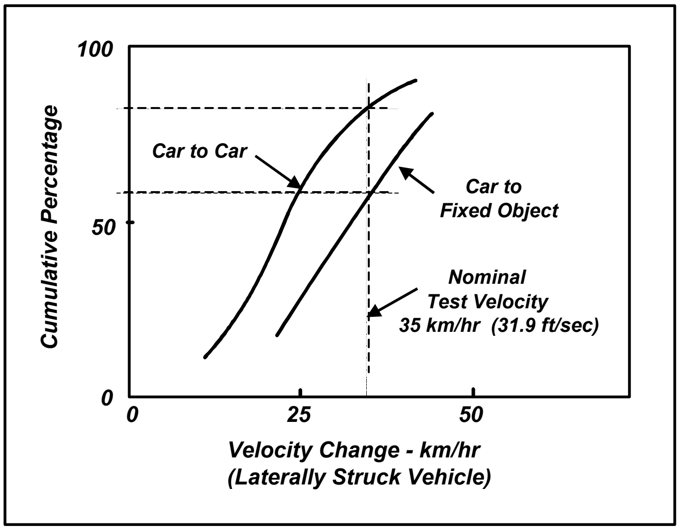

Figure 7 - Impact Environment and Nominal Test Velocity for Automotive Research

The higher velocity change and G levels that an occupant in a sideward facing seat is exposed to in an aircraft accident can significantly affect the occupant's injury levels. Human subject and cadaver tests have indicated that impact injuries are sensitive to both velocity change and G levels.

The occurrence and severity of neck injuries in automotive side impacts are also minimized to some degree by the interior design of the automobile. A near-side occupant's head/neck tend to strike the side pillar, side glass, or headliner in an automobile side impact. These items tend to provide some head/neck support during the impact. The far-side occupant typically rotates inboard out of the upper torso restraint and direct neck loads do not occur. The severity of the impact and the occupant's support and restraint system loading differ significantly for an occupant exposed to an automotive side impact as compared to an occupant exposed to an aircraft accident seated in a sideward facing seat. These cited differences can change occupant injury mechanisms and they limit the implementation of automotive side impact protection strategies for aircraft.

<u>TRANSAFE Sideward Facing Seat Research</u>

Sideward facing seats are not typically found in automobiles however they can be found in military transport ground vehicles. A research project known as TRANSAFE was initiated by the Australian Army with Monash University in Australia to address the survivability of solders seated in the rear of military vehicles when involved in a crash (Ref. 6). Their research activity focused on a military troop transport vehicle commonly known as a Perentie 4x4 Utility vehicle that is based on a Land Rover 110. The Perentie 4x4 Utility vehicle is capable of carrying eight unrestrained soldiers in the rear and two restrained soldiers in the front cabin. The soldiers are seated in the rear on sideward facing bench seats. The Australian Army operates a fleet of 3,500 of these Land Rover based vehicles in various configurations.

The TRANSAFE research activities included full-scale impact tests and MADYMO seat/occupant computer models that were used to investigated the occupant impact protection characteristics of the existing Perentie 4x4 seats and a number of proposed modifications aimed to improve the crash safety of those seats. Impact tests with a variety of seating devices and restraint system configurations were conducted at the Australian New South Wales, Roads and Traffic Authority, CRASHLAB Sled Test Facility. A test pulse representing a velocity change of 48 km/h was used for all tests. That velocity change is consistent with the 44 ft/sec velocity change found in 14 CFR Part 25, §25.562, the seat dynamic performance standards for transport category airplanes. The test pulse used in this study depicted in Figure 8 was derived from acceleration data acquired during a 48 km/h full frontal barrier impact test of a Land Rover vehicle. The longitudinal with yaw test pulses given in the Federal Aviation Regulations for the certification of general aviation aircraft, rotorcraft, and transport airplane categories aircraft seats are also shown on Figure 8 for comparison.

All tests in the TRANSAFE study were conducted with 49 CFR Part 572, Subpart E, 50% Hybrid III Anthropomorphic Test Dummies (ATDs) installed in the seat/restraint systems. The ATDs' head, chest, and pelvic accelerations, and neck loads were measured in all the tests. Of particular interest are the neck load measurements acquired for two tests.

They are of interest because the configurations of the seat/restraint systems evaluated in both of those tests are comparable to sideward facing seat configurations found on civil aircraft.

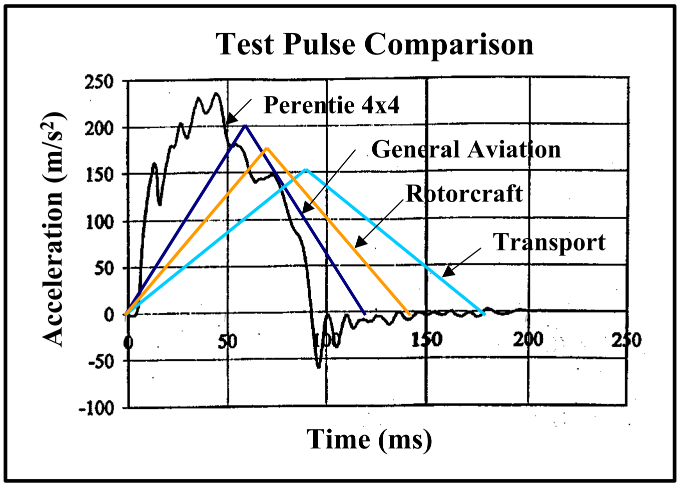

Figure 8 - TRANSAFE - Civil Aircraft Seat Test Pulse Comparison

The first test of interest (TS1) evaluated a standard forward facing Perentie seat placed in a sideward configuration occupied by a single ATD restrained with a three-point "Y" restraint system. It was noted in the discussion of the results of this test that; "the neck was flicked in lateral hyperflexion generating a serious, if not life threatening injury". The displacements of the ATD's head/neck and torso seen during the TS1 test appear comparable to that seen in Figure 9 from a similar sled test conducted at the FAA's CAMI test facility. The acquired ATD's neck loads also compare well between these two tests. A summary of the TRANSAFE acquired neck loads can be found in Table 1.

Test	Sled Accel.	Peak Neck Shear Force			Peak Neck Bending Moments		
	G's	X Axis N	Y Axis N	Z Axis N	X Axis Nm	Y Axis Nm	Z Axis NM
TS1	24.1	160 -590	1320 -271	2443 -138	22.4 -96.6	16.1 -40.8	8.8 -35.7
TMB5 1st ATD	25.8	248 -525	2387 -225	5213 -3220	192.1 -83.9	31.2 -24.1	5.1 -34.6
TMB5 2nd ATD	25.9	794 -166	1140 -238	2938 -330	39.6 -95.9	81.2 -17.4	24.6 -31.7

Table 1 - Summary of Acquired Neck Loads

The second test of interest (TMB5) used a standard Perentie sideward facing bench seat with three ATDs placed on the seat each restrained with a three-point upper torso restraint system. Significant interaction between the three ATDs was seen during the test. It was noted in the discussion of the results of this test that; "Significant loading of the neck and upper torso is apparent. A peak neck tension load of 2938N was generated, which at a minimum would result in a serious injury." A number of other comments related to the potential for head injury were also found in the discussion of the test results. Again the displacements of the ATDs' head/neck and torso seen during this test appeared comparable to that seen in similar sled tests conducted at the FAA's CAMI test facility. A summary of the TRANSAFE acquired neck loads for this test can also be found in Table 1.

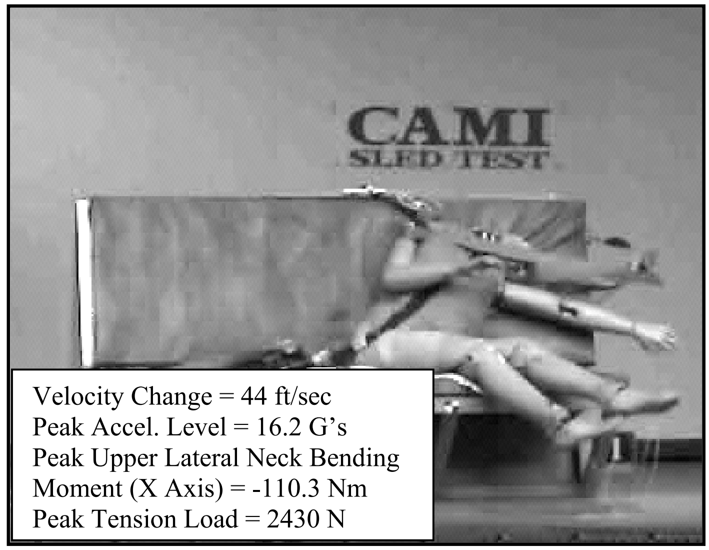

Figure 9 - Example of CAMI Sled Test

One cited conclusion from the TRANSAFE research program is; "The bench seat and lap belts, bench seat and lap sash and individual seat harness systems used in side facing seating configurations in a Perentie 4x4 represent a high probability of serious if not life threatening injury to the seat occupant. The prevalent types of injuries would be brain damage an a results of head impacts, neck damage as a result of neck flexion, extension and rotation and internal thoracic damage as a result of high chest accelerations".

The results of the TRANSAFE research program are of interest for some of the seat/restraint systems evaluated in that program are comparable to typical sideward facing seat configurations found on aircraft. The severity of the test environment used in the TRANSAFE research program is also comparable to the test environment defined in the seat dynamic performance standards for civil aircraft. The tests results and the conclusions from the TRANSAFE test series provide insight into the potential of impact injury of aircraft occupants seated in sideward facing seats if exposed to an aircraft accident.

HUMAN INJURY CRITERIA

Human subject Tests

A number of lateral impact tests with live subjects and cadavers have been conducted. All of those tests were conducted at velocity changes (less than 22 ft/sec) and G levels (less than 12 G's with live subjects) that were less than those found in 14 CFR Part 25, §25.562. Most of those tests were conducted with full body upper torso support. Typically head accelerations (linear and angular) and displacements were recorded along with occupant physiological response. The maximum head resultant accelerations measured during the human subject tests and other cadaver tests are summarized in Figure 10. That data could form the basis of proposed injury criteria.

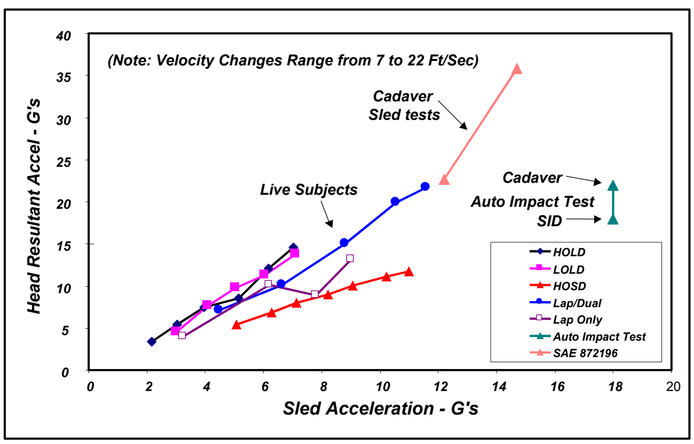

Figure 10 - Summary Results of Lateral Impact Tests

U.S. Air Force Lap Belt Only Restraint Tests

A series of controlled deceleration experiments was performed with 37 human male (young healthy U.S. Air Force) volunteers to determine, if possible, human tolerance to lateral impacts while restrained in a seat with a lap belt (Ref. 7). The subjects were exposed in 50 different experiments to average impact G levels that ranged from 3.25 to 9.02 G's for a duration of 0.3 to 0.1 seconds. Velocity changes ranged from 14.2 to 15.2 ft/sec. No permanent physiological changes were noted. Minor physical complaints (sore necks for up to 3 days) were reported by 50% of the subjects when exposed to an average G level of 6.25 or more. Increasing danger from head/neck lateral flexion of up to 30 degrees from the vertical was cited for halting the experiments at the 9.02 average G level. The maximum head resultant accelerations measured during these tests are shown on Figure 10.

U.S. Air Force Lap Belt and Dual Upper Torso Harness Restraint Tests

A second series of controlled deceleration experiments was performed with 52 young human male (young healthy U.S. Air Force) volunteers to determine, if possible, human tolerance to lateral impacts while restrained with a combination seat belt and upper torso harness (Ref. 8). The upper torso harness consisted of two straps attached to the seat at the shoulder line that passed over the shoulders parallel to the vertebral column and attached to the lap belt. The subjects were exposed in 87 different experiments to average impact G levels of 4.47 to 11.59 G's for durations of 0.22 to 0.09 seconds. Head/torso deflections ranged from 19 to 57 degrees. No permanent physiological changes were noted.

Minor subjective physical complaints (neck muscle stiffness) were reported by more than 60% of the subjects when exposed to average G levels of 8.3 or more. The possibility of cardiovascular involvement halted the experiments after two subjects were exposed to the 11.59 average G pattern (12 G series). The maximum head resultant accelerations measured during these tests are shown on Figure 10.

U.S. NAVY Lap Belt and Dual Upper Torso Harness Restraint Tests

A third series of human male (young healthy U.S. Navy) volunteer experiments has been conducted to measure the inertial response of the head and the first thoracic vertebra (T_1) to +Gy whole body impact acceleration (Ref. 9). Three categories of sled acceleration profiles were used: high onset, long duration (HOLD) with G levels from 2 to 7.5 G's with a sled velocity change of 6.5 meters/sec (21.4 ft/sec); low onset, long duration (LOLD) with the same peak acceleration and velocity change levels; and high onset, short duration (HOSD) with G levels from 5 to 11 G's. No physiological changes were noted in any of the tests. The maximum head resultant accelerations measured during these tests are shown on Figure 10.

The aforementioned human subject tests as one would expect were conducted at impact conditions that were below the severity level that would cause any serious or permanent injuries. The results of the human subject tests may provide some insight with respect to non-injurious human neck tolerance limits but their usefulness with respect to defining an injurious human neck tolerance limit is limited.

Cadaver Sled Tests

A review of high G level sled-cadaver tests was initiated to find if any of those tests might be useful in forming a basis for the definition of an injurious human neck tolerance limit. It was found that lateral impact studies (sled tests at 12.2 to 14.7 G's/up to 28.2 ft/sec) were conducted with cadavers to investigate the human head/neck response (Ref. 10). A summary of the test conditions evaluated in this study is given in Figure 11. The head linear acceleration levels in this study ranged from 22.7 to 35.8 G's. The maximum neck moments at the occipital condyles for one of the cadavers was estimated to be 55 Nm (487 in-lbs.). That subject also experienced a maximum head angular acceleration of 2526 rad/sec^2. The results of autopsies of the subjects found no injuries in the head/neck region except in one test where cervical fractures occurred.

Summary of "High Severity" Impact Conditions

Test Number	Peak Sled Deceleration G's	ΔT Milliseconds	Initial Sled Velocity Meters/Second (Ft/Sec)
MS 249	12.2	55	6.08 (19.9)
MS 297	14.2	48	6.19 (20.3)
MS 360	14.6	58	8.61 (28.2)
MS 361	14.0	46	6.25 (20.5)
MS 375	14.7	37	6.3 (20.7)
MS 376	12.2	48	6.3 (20.7)

Figure 11 - Cadaver-Sled Impact Test Conditions

Two data points that represent the maximum head resultant accelerations measured during this study are shown on Figure 10. Many of the head acceleration and neck moment levels measured during this study exceed those measured in any other test series. Some of those values will be recommended as tolerance limits for lateral neck loading.

Cadaver Car Tests

The results of seven car-to-car lateral collisions with belted far-side rear seat occupants were documented in Ref. 11. The test subjects, cadavers and a US SID dummy, were restrained with a 3-point belt that had an inboard upper anchoring point for the shoulder belt. The collision velocity was 50 km/hr. A velocity change of 6.5 m/sec (21.4 ft/sec) and an 18-G's peak (spike) was recorded on the struck vehicle. In the cadaver tests, the maximum resultant acceleration measured at the clivus was 18 G's (an average of 5 tests). In the test with a US SID dummy a maximum acceleration level of 21.7 G's was recorded at the C.G. of the head. These data points are also included on Figure 10. Spikes in the acceleration data shift these data points from the data cluster shown on Figure 10. An "effective acceleration" value, estimated to be in the 12 to 14 G's range, would place the data points obtained from this study within the data cluster found on Figure 10. A typical acceleration time history data plot recorded in the cadaver-car impact tests series is illustrated in Figure 12.

Typical Acceleration-Time History of Impact

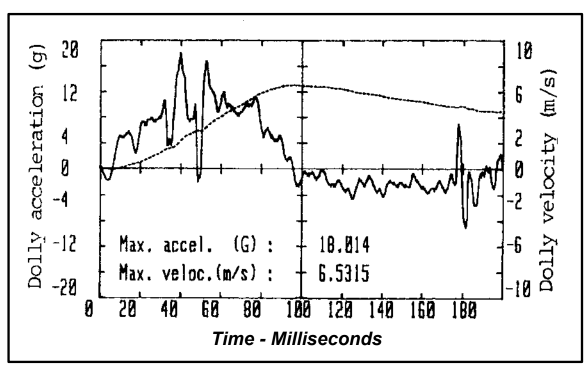

Figure 12 - Cadaver-Car Impact Test Results

Analysis of the high-speed films found that the far-side cadavers experienced lateral head/neck bending angles of 40 to 65 degrees. The calculated head angular velocities for the far-side cadavers were between 13 and 22 rad/sec. Head angular accelerations were between 350 and 644 rad/sec^2.

No head, thorax or pelvic injuries were observed. Belt-induced minor injuries at the skin on the neck, the neck muscles, and cervical spine were observed with a MAIS 1. The calculated values of the head angular velocities and angular accelerations were noted by the authors to be in agreement with the observed minor injuries in the neck region.

Other Studies

Some other studies supplement and/or confirm the aforementioned research activities. Wismans (Ref. 12) in his analyses of the neck responses of the human volunteers in the lateral impact tests summarized in Ref. 9 confirmed the maximum lateral head/neck flexion (48 to 58 degrees) recorded in that test series. He suggested a 52 degrees limit. Wismans calculated the maximum lateral neck moments near the occipital condyles for that test series to be approximately 50 Nm (442 in-lbs.) and the maximum value of torque about the vertical axis of the head to be 15 Nm (133 in-lbs.).

Gadd (Ref. 13) suggested a 60 degrees neck lateral flexion limit for elderly individuals. His suggestion is based on the results of static and dynamic tests of dissected necks. His study also indicated that the resisting moment (neck load) for a given neck deflection is greater under dynamic load as compared to a static load.

Schneider (Ref. 14) evaluated the neck lateral flexion characteristics of 96 female and male subjects. Their ages ranged from 18 to 74 years old. His study showed that the limits of neck lateral flexion ranged from 86 degrees for the young subjects to 48 degrees for the elderly subjects.

A kinematics analysis of the head/neck unit has been conducted in 37 simulated traffic accidents in order to investigate correlation between neck response and injuries (Ref. 15). Belted fresh human cadavers whose ages range from 18 to 74 years have been used in tests as front and rear seat passengers. The analyzed data included 23 frontal collision barrier impacts with impact velocities of 30 km/hr, 50 km/hr and 60 km/hr. Also analyzed and of interest here were fourteen, 90-degree car-to-car lateral collisions with near-side passengers (6 cases) as well as far-side rear seat passengers with an inboard upper anchoring point for the shoulder belt (8 cases). Both sled and car-to-car impact tests were conducted. In the lateral impact tests the velocity changes ranged from 30 to 35 km/hr (27.3 to 31.9 ft/sec) for the sled tests and were 25 km/hr (22.7 ft/sec) for the car-to-car collision tests.

The head/neck response was found dependant on the type of the collision. For the lateral collision cases, considering only the far-side occupants, head/neck bending angles ranged from 26.9 to 80 degrees while most were between 53.9 to 58.5 degrees. The maximum value of the recorded head angular acceleration was 2601 rad/sec^2. The maximum value of the acceleration recorded along the head path was 26.67 G's.

Again considering only far-side occupants, most experienced a cervical spine injury severity of AIS 1 (sprains) while one AIS 3 (fracture) and one AIS 5 (spinal cord laceration) were found. The authors noted that the results indicate that AIS 1 injuries occur at an head/neck angle of 27 degrees for lateral collisions. A summary of the locations and severity of the vertical column injuries observed in the side collision tests for this study is given in Figure 13.

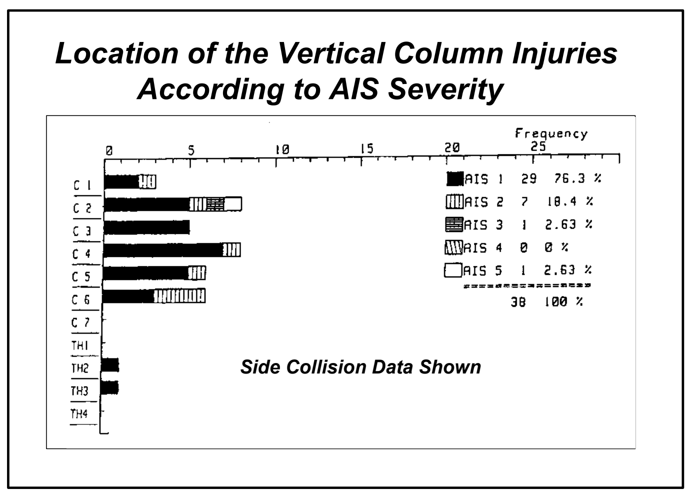

Figure 13 - Results of Lateral Impact Tests

NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION (NHTSA)

The NHTSA has recently completed the development of improved injury criteria for the assessment of advanced automotive restraint systems (Ref. 16). The development of this improved injury criteria, for neck flexion (forward) and extension (aft) loading, was driven by the need to assess the performance of advanced airbag systems. The new NHTSA neck flexion/extension load criteria may serve as a point of reference in the development of lateral neck load injury criteria but one should keep in mind that the load paths and strength limits differ between neck flexion/extension loading and neck lateral flexion loading.

The NHTSA neck injury criteria take the form of peak tension and compression axial force limits and combined axial and bending Nij intercepts criteria. The NHTSA Nij intercepts and independent axial force limits are given in Table 2 and graphically depicted in Figure 14 for the in-position, 50% male (Hybrid III ATD).

Dummy Size	Peak Limits			
50% Male	Tension (N)		Compression (N)	
	4170		4000	
	Nij Intercepts			
50% Male	Tension (N)	Comp (N)	Flexion (Nm)	Exten (Nm)
	6806	6160	310	135

Table 2 - NHTSA Nij Criteria for 50% Male

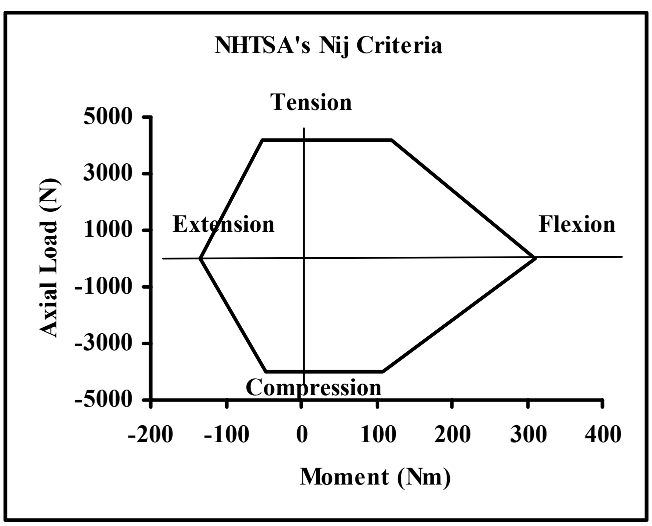

Figure 14 - NHTSA Nij Criteria for 50% Male

The NHTSA Nij criteria were formulated for frontal crash testing and it currently does not consider neck torsional load or lateral bending load in evaluating the potential for neck injury. NHTSA is initiating further research tasks directed to address the neck torsional load and lateral bending load tolerance limits.

The NHTSA peak tension and compression axial load limits are considered robust and those limits can readily be used in assessments of the potential of neck injury in certification tests of aircraft seats.

CONCLUSIONS

This review revealed a paucity of data that could be used to develop human neck injury criteria for lateral neck shear and bending loads. In the past most of the research activities have rightly focused on the more common injury modes that are associated with frontal impacts and forward facing seats. Lateral neck injury modes have not had much emphasis. However with the proliferation of sideward facing seats in business jet aircraft and the automotive industry's initiative to improve the occupant impact protection level for side impact automobile accidents new emphasis has been placed on the definition of human tolerance limits for lateral loading impact conditions.

Aircraft sideward facing seat research studies were found to be limited to evaluations of the overall dynamic performance characteristics of sideward facing seats. Those studies typically evaluated the potential of occupant injury using the automotive side impact criteria, investigated the potential existence of other injury mechanisms unique to aircraft seats and their installation, and evaluated the performance of various seat/restraint system design concepts. However all of those studies stopped short of defining any new human tolerance limits for lateral loading impact conditions.

A review of automotive safety research activities found that those studies were with one noted exception limited to investigating the impact environment and injury modes associated with car-to-car side impacts. It was found that there are significant differences between the automobile and the aircraft impact environments, injury modes, and seating.

A review of head/neck injury modes found that head injury in automobiles, specifically brain injuries, account for more than 60% of the total HARM in the head body region. Consequently much of the past automotive research activities were directed towards enhancing occupant head injury protection. Neck injury (other than whiplash) has not been a dominant occupant injury mode in automobile accidents and thus neck injury research has been limited.

The automobile side impact environment may in part minimize the occurrence of serious neck injuries. The lateral velocity change seen in an automobile side impact condition is significantly less than the lateral velocity change that an occupant in a sideward facing seat can see in an aircraft accident. Automotive side impact research tests are thus typically conducted at velocity change levels that are less than those found in the seat dynamic performance standards for aircraft seats. Additionally the interior design of the automobile may also to some degree minimized the severity of side impact conditions. Consequently little data could be gleaned from automotive side impact research studies that could form the basis of enhanced tolerance limits for lateral neck loading for aircraft applications.

One exception to the above discussion regarding the severity of the automotive impact environment was the Australian Army's TRANSAFE research program. That research program was conducted with a sideward facing seat at vehicle velocity changes levels that were consistent with those found in the seat dynamic performance standards for aircraft seats. The TRANSAFE research program did demonstrate the potential for occupant neck injury but it did not establish any new human tolerance limits for lateral neck loading.

Human subject tests were conducted at impact conditions (velocity change levels less than 22 ft/sec) that were below the severity level that would cause any serious or permanent injuries. The results of the human subject tests may provide some insight with respect to non-injurious human neck tolerance limits but their usefulness with respect to defining an injurious human neck tolerance limit is limited.

A number of automotive cadaver-sled and cadaver-car lateral impact test results were reviewed. It was found that all of the cadaver impact test programs were conducted at velocity change levels consistent with the automotive accident impact environment that is less than the lateral velocity change that an occupant in a sideward facing seat can experience in an aircraft accident. Most of the neck injuries seen in those studies were at an AIS 1 level while one AIS 3 (fracture) and one AIS 5 (spinal cord laceration) were found.

A number of other lateral head/neck flexion and impact response studies and NHTSA's improved Nij neck injury criteria were also reviewed. However none were found to provide any definitive tolerance limits for lateral neck loading.

RECOMMENDATIONS

Two forms of candidate tolerance limits for lateral neck loading are proposed. These limits are based on the maximum measured kinematics and load values found in this review most of which appear to reach the onset of minor injury and the threshold of serious injury.

1. The first form is based on the kinematics response of the occupant.

- Lateral neck flexion not to exceed 60 degrees. This angle is measured between the head anatomical vertical axis and the mid-sagittal plane of the ATD.

  Neck flexion was a cited concern by many of the researchers. Figure 9 illustrates the potentially injurious neck flexion that could be imposed on an occupant of a sideward facing aircraft seat.

- Peak linear acceleration not to exceed 36 G's measured at the C.G of the ATD's head.

- Peak head angular acceleration of the ATD's head not to exceed 2600 rad/sec^2.

- Where head strike with structures or other obstacles occurs the kinematics based limits are not to be exceeded up to the point of head contact. During head contact HIC not to exceed 1000.

2. The second form of tolerance limits is based on the peak axial loads and moments measured in the neck of the occupant.

- Lateral neck moment (Mx) not to exceed 536 in-pounds (i.e., 487 inch-pounds increased 10% to account for muscle strength) or 60 Nm measured at the upper neck load cell of an ATD.

- The maximum axial loads not to exceed 940 lbs. force (4170 N) tension and 900 lbs. force (4000 N) compression.

- Nij injury criteria using the NHTSA's intercepts with the above lateral moment limit as shown in Table 3.

Dummy Size	Peak Limits		
50% Male	Tension (N)		Compression (N)
	4170		4000
	Nij Intercepts		
50% Male	Tension (N)	Comp (N)	Lateral Moment (Nm)
	6806	6160	60

Table 3 - Proposed Lateral Load Nij Criteria

A graphical depiction of the proposed Nij lateral load neck injury criteria is shown in Figure 15.

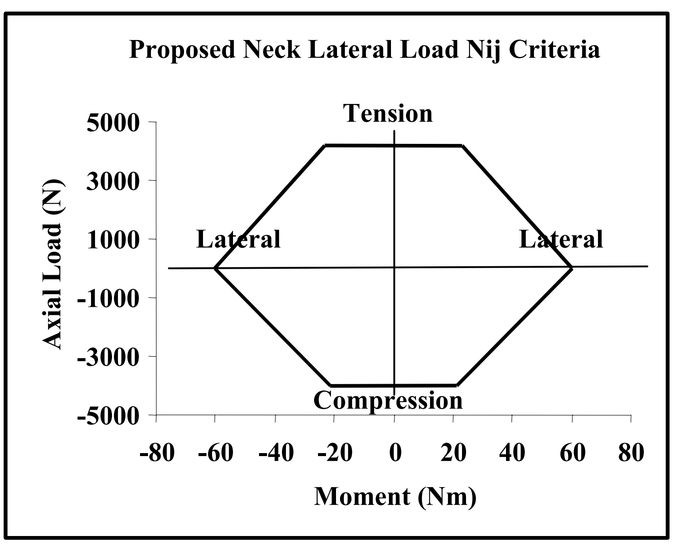

Figure 15 - Proposed Lateral Load Nij Criteria

These recommendations are based on the scope of the current data review. It is believed that these criteria represent thresholds of serious human neck injury. The FAA and NHTSA are initiating research tasks directed to further define tolerance limits for lateral neck loading. These recommendations may be revised as new data become available.

AUTHOR'S NOTES

The comments and recommendations found in this paper are those of the author and they may not represent official FAA policy or current regulations.

Most of the data presented in this paper were reproduced from the noted reference sources with minimal or no change to avoid misrepresentation. As a result two standards of units may be found throughout this paper. The author apologizes for the added difficulty of comprehension this may create for the reader.

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