The Third Triennial International Aircraft Fire and Cabin Safety Research Conference

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

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Example of Business Jet Cabin Interior

Review of Side Facing Seat Research and Neck Injury Criteria

Aircraft Side Facing Seat Research Studies
- CAMI/GESAC
- CAMI/NIAR

Automotive Impact Environment and Safety Research

Human Subjects Impact Tests

Cadaver Impact Tests
- Sled Tests
- Car Tests

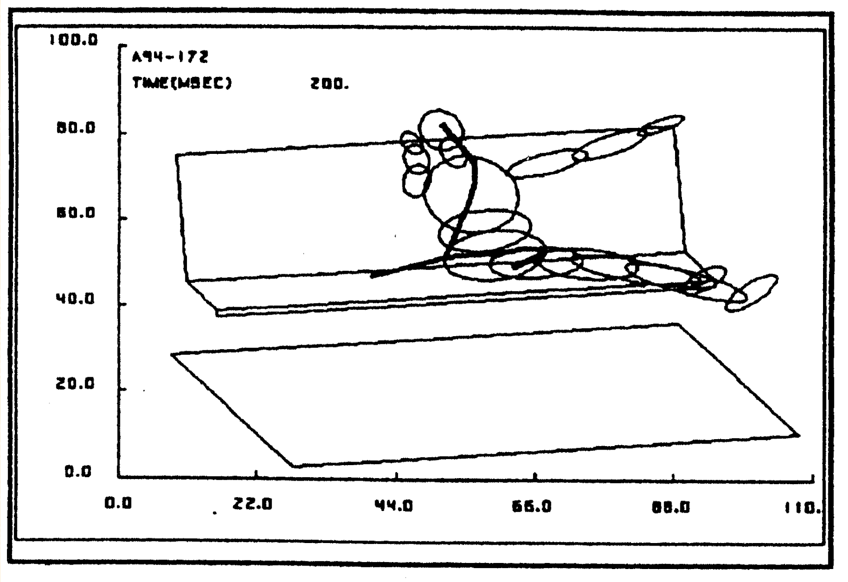
Other Related Studies

Candidate Neck Injury Criteria

Review of Aircraft Side Facing Seat Research Studies - CAMI/GESAC

An early study by CAMI and GESAC was directed to investigate the potential for injury of passengers seated in a side facing aircraft seat.

Computer simulations and full scale tests were integral elements of that study.



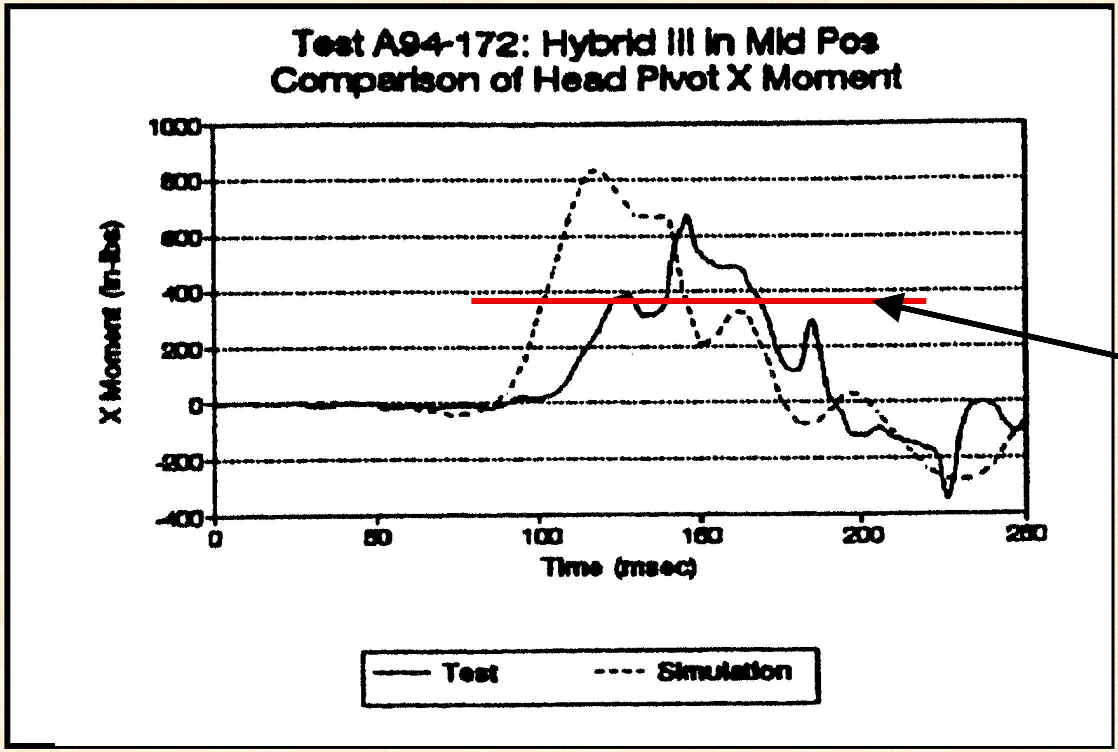
Example of Occupant Computer Simulation at T = 250 MS

FAR 25.562(b)(2) Impact Pulse

Ref. Rangarajan, N., et al, SAE Technical Paper No. 951164, "Safety of Side Facing Seats in General Aviation Aircraft", May, 1995.

Review of Aircraft Side Facing Seat Research Studies -CAMI/GESAC

The early CAMI/GESAC study found that the only injury parameter that consistently exceeded the tolerance value was the lateral neck moment.



Example Data Plot

Approximate Tolerance Level

Comparison of Neck x Moment

Review of Aircraft Side Facing Seat Research Studies - CAMI/NIAR

Objectives

Investigate potential injuries corresponding to single and multiple-occupant (divan-type) SFS configurations

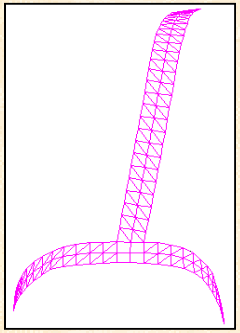
To demonstrate an "equivalent level of safety" as compared to those on forward or aft-facing seats

Identify potential configuration(s) that provide highest level of occupant protection

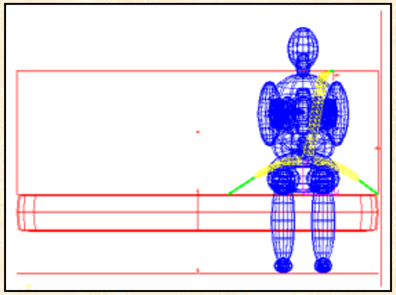
Ref. Lankarani, H.M., et al, SAE Technical Paper No. 99GCRAM-22, "Compliance Criteria For Side Facing Seats", 1999.

Review of Aircraft Side Facing Seat Research Studies - CAMI/NIAR

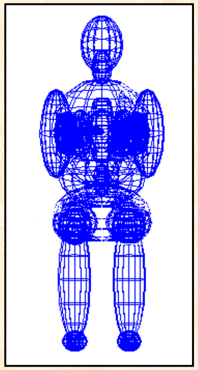
Methodology



FEM Belt

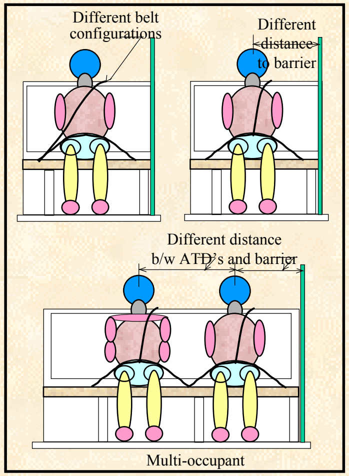


Correlation between test and analytical results



MADYMO Occupant Model

Sled Test



Conduct Series of Parametric Studies using MADYMO

Establish a Set of Injury/Pass Fail Criteria along with Design Guidelines and Testing Procedures

Review of Aircraft Side Facing Seat Research Studies - CAMI/NIAR

Noted Conclusions (partial)

- *Limiting Compression based criteria*
  - *Is sensitive to energy transmitted to rib cage*
  - *Padding on the barrier showed no significant effect on deflections*
  - *Avoidance of contact may be the only effective means*
- *When H-II ATD was placed aft of the SID or EuroSID-1*
  - *Acceleration and compression based criteria tended to be somewhat higher*
  - *Attempts to quantify the effects of body-to-body contact were not conclusive*
- ***HIC and neck lateral moments exceeded the threshold. For providing equivalent level of safety, these need to be addressed***

Review of Automotive Impact Environment and Safety Research

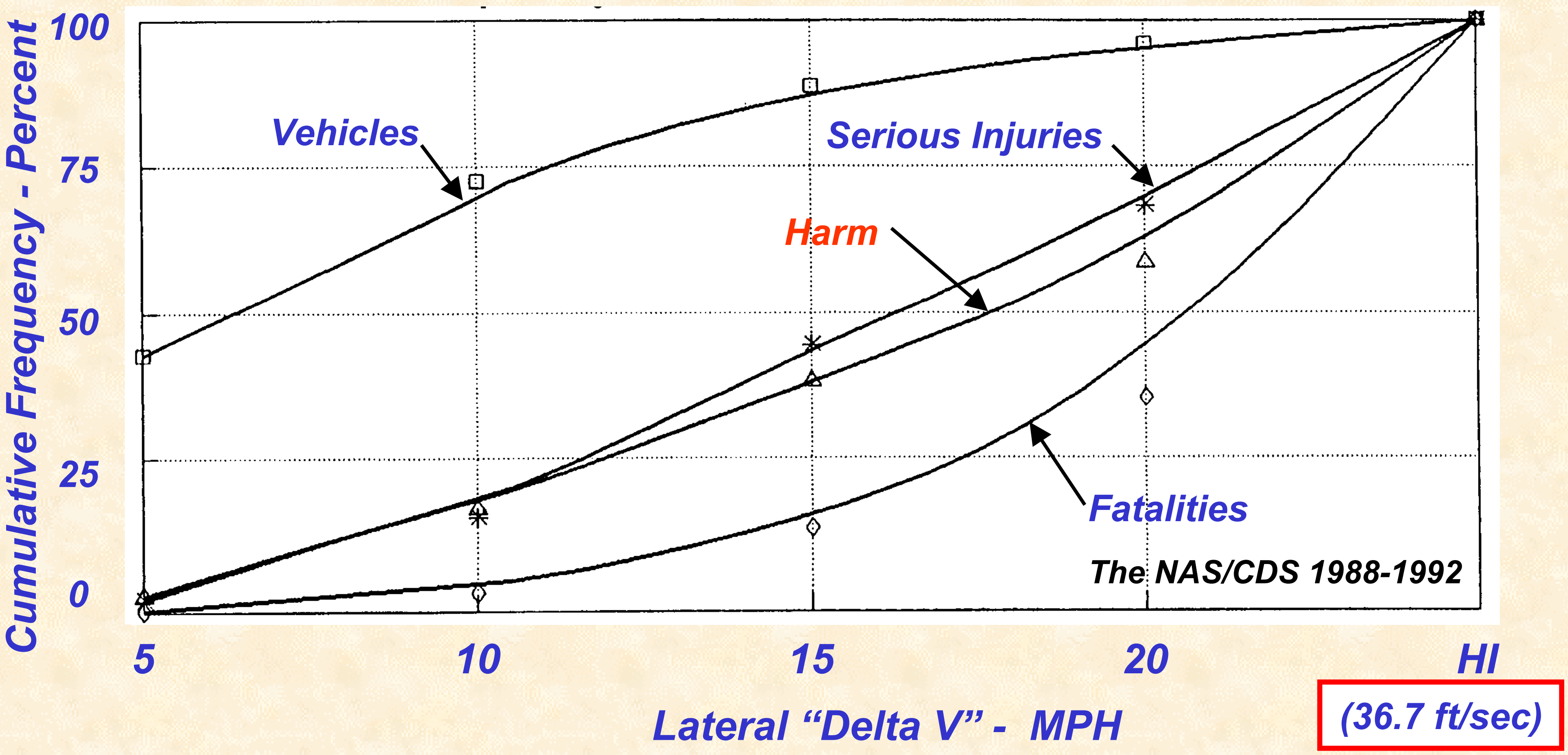
Comparison of the Automotive and Aircraft Impact Environments

Accident Severity Levels

The severity of an automobile side impact (G level and velocity change) is typically less than the impact conditions found in FAR 25.562.

Automotive accident studies have found that a 35 km/hr (31.9 ft/sec) velocity change represents about an 80th percentile level for injury producing mechanisms as compared to the 44 ft/sec velocity change found in FAR 25.562.

Cumulative Distribution of Each Shown Population Among Lateral "Delta V" in Side impacts



Ref: DRAFT, "Comprehensive Characterization of Light Vehicle Side Impacts", An Investigation Conducted for the FHWA/NHTSA Crash Analysis Center at George Washington University, VA, September 1994.

Comparison of the Automotive and Aircraft Impact Environments

Occupant Injury Potential

Human subject and cadaver tests have indicated that human impact injuries are sensitive to both G and velocity change levels.

The aircraft's higher G level and velocity change can significantly affect occupant injury levels.

Comparison of the Automotive and Aircraft Impact Environments

Occupant Injury Potential

Neck injuries in automotive side impacts are minimized to some degree by the interior design of the automobile.

In an automobile side impact the near-side occupant’s head/neck tend to strike the side pillar, side glass, or headliner that provides some support.

The far-side occupant typically rotates inboard out of the upper torso restraint and direct neck loads do not occur.

Review of Automotive Impact Environment and Safety Research

Neck injury (other than whiplash) has not been a dominant occupant injury mode in automotive accidents.

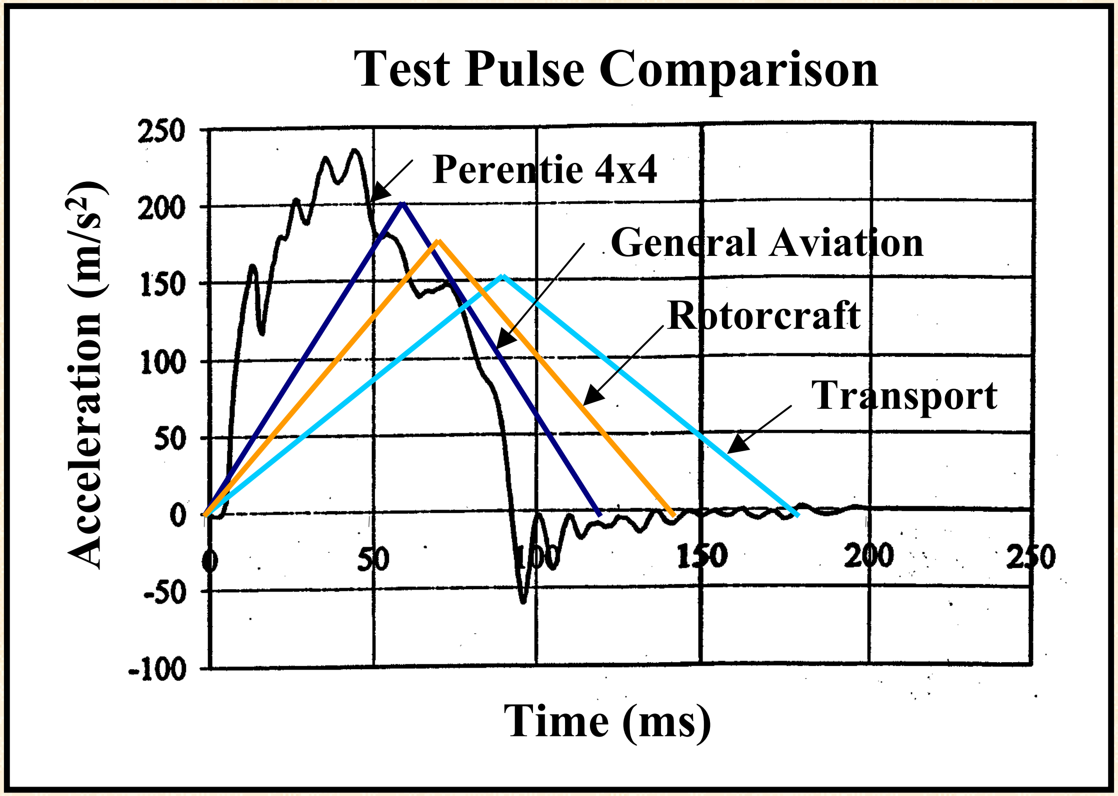
One automotive accident study found that in car-to-car side impacts neck injury is the most severe injury for a little more than 20% of the total head/neck region injuries.

However those neck injuries are not typically serious and only account for approximately 8% of the total HARM (a measure of the cost to society).

Consequently much of the automotive research directed towards occupant safety relates to occupant head injury protection.

Australian TRANSAFE Research Study

Investigated the Crash Survivability of Troops Seated in the Australian Army Perentie 4X4 (Land Rover 110) Transport Vehicle



Comparison of TRANSAFE and Civil Aircraft Seat Test Pulse Comparison

Australian TRANSAFE Research Study Conclusion

The Side Facing Seat Configurations in a Parentie 4x4 Represent a High Probability of Serious if Not Life Threatening Injury to the Seated Occupant

Example of the Results From a Comparative CAMI Sideward Facing Seat Test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Review of Human Subjects 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) less than those found in FAR 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.

Review of Human Subjects Tests
Young Healthy U.S. Navy Male Volunteers With Lap Belt and Dual Upper Torso Harness

Conducted to measure the inertial response of the head and the first thoracic vertebra (T_1) to +Gy whole body impact acceleration. No physiological changes were noted.

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;

High onset, short duration (HOSD) with G levels from 5 to 11 G's.

Ref. Ewing, C.L., et al, SAE Technical Paper No. 770928, "Dynamic Response of the Human Head and Neck to +Gy Impact Acceleration", 1977.

Cadaver Sled Impact Tests Review
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)

Ref. Bendjellal, F., et al, SAE Technical Paper No. 872196, "Head and Neck Responses Under High G-Level Lateral Deceleration", 1987.

Cadaver Sled Impact Tests Review
Summary of Results

Lateral impact studies (sled tests at 12.2 to 14.7 G's /28.2 ft/sec) were conducted with cadavers to further investigate the human head/neck response.

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.

Cadaver-Car Impact Tests Review

Seven car-to-car lateral collisions with belted far-side rear seat occupants were conducted.

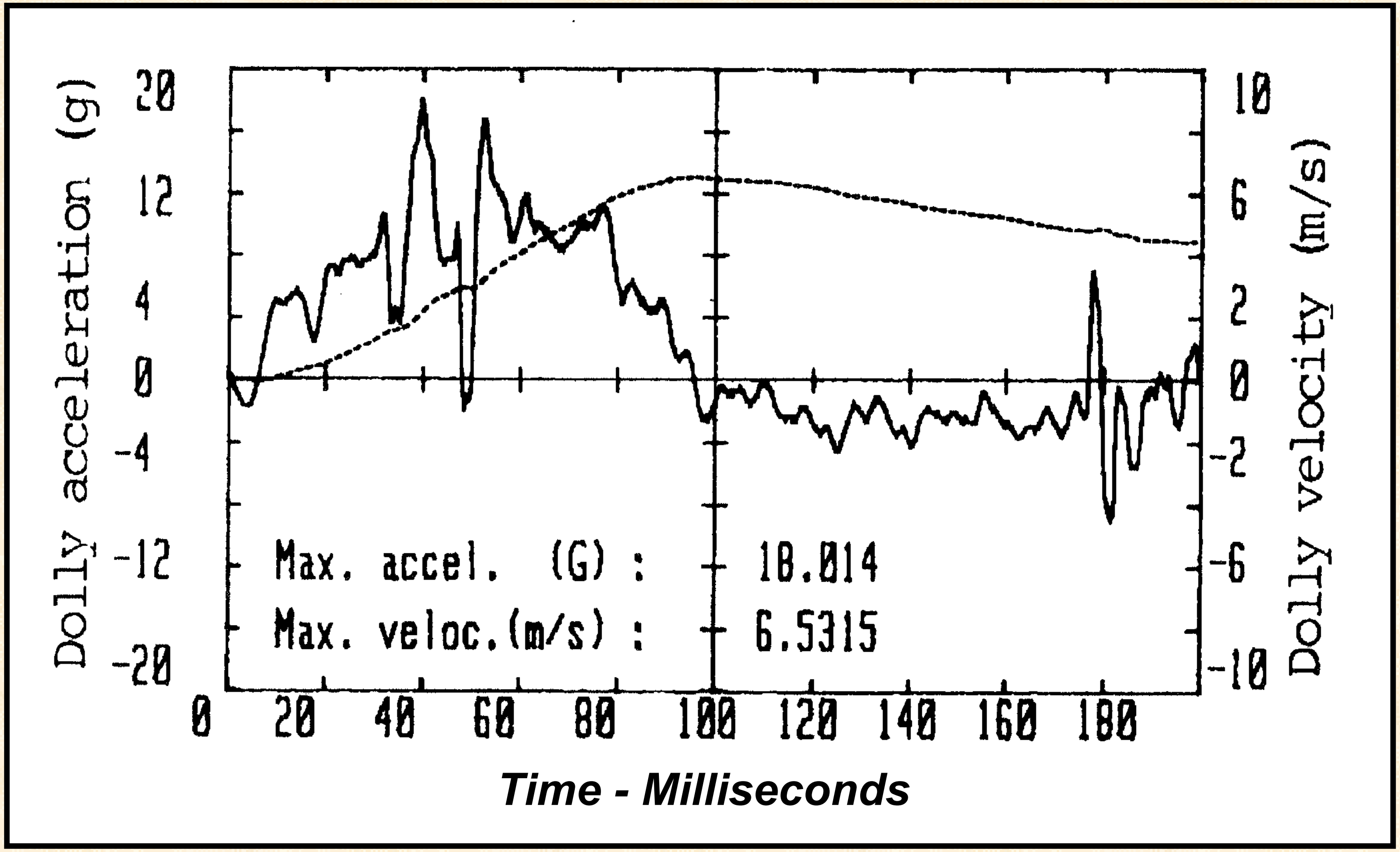
The test subjects, cadavers and a US SID dummy, were restrained with a 3-point belt that had an inboard upper anchoring point for the shoulder belt.

The collision velocity was 50 km/hr.

That resulted in a velocity change of 6.5 m/sec (21.4 ft/sec) and an 18-G's peak (spike) as recorded on the struck vehicle.

Ref. Kallieris, D., and Schmidt, G., SAE Technical Paper 902313, "Neck Response and Injury Assessment Using Cadavers and the US-SID for Far-Side Lateral Impacts of Rear Seat Occupants with Inboard-Anchored Shoulder Belts", 1990.

Cadaver-Car Impact Tests Review
Typical Acceleration-Time History of Impacts



Ref. Kallieris, D., and Schmidt, G., SAE Technical Paper 902313, "Neck Response and Injury Assessment Using Cadavers and the US-SID for Far-Side Lateral Impacts of Rear Seat Occupants with Inboard-Anchored Shoulder Belts", 1990.

Cadaver-Car Impact Tests Review
Summary of Results

High-speed film analyses found that the cadavers experienced lateral head/neck bending angles of 40 to 65 degrees.

The calculated head angular velocities for the cadavers were between 13 and 38 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.

Review of Automotive Impact Environment and Safety Research

Other Studies supplement and/or confirm the aforementioned research activities.

A kinematic analysis of the head/neck unit has been conducted in 37 simulated traffic accidents in order to investigate correlations between neck response and injuries.

Belted fresh human cadavers whose ages range from 18 to 74 years have been used as front and rear seat passengers.

Analyzed were fourteen, 90-degree car-to-car lateral collisions with near-side passengers (6 cases) and far-side rear seat passengers (8 cases) with an inboard upper anchoring point for the shoulder belt.

The velocity changes ranged from 30 to 35 km/hr (27.3 to 31.9 ft/sec) for the sled tests and 25 km/hr (22.7 ft/sec) for the car-to-car collision tests.

Ref. Kallieris, D., et al, SAE Technical Paper No. 912916, "Considerations for a Neck Injury Criteria", 1991.

Review of Automotive Impact Environment and Safety Research

Other Studies supplement and/or confirm the aforementioned research activities

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 recorded head angular acceleration was $\boxed{2601\ \text{rad/sec}^2}$.

The maximum acceleration recorded along the head path was 26.67 G's.

Ref. Kallieris, D., et al, SAE Technical Paper No. 912916, "Considerations for a Neck Injury Criteria", 1991.

Review of Automotive Impact Environment and Safety Research

Other Studies supplement and/or confirm the aforementioned research activities

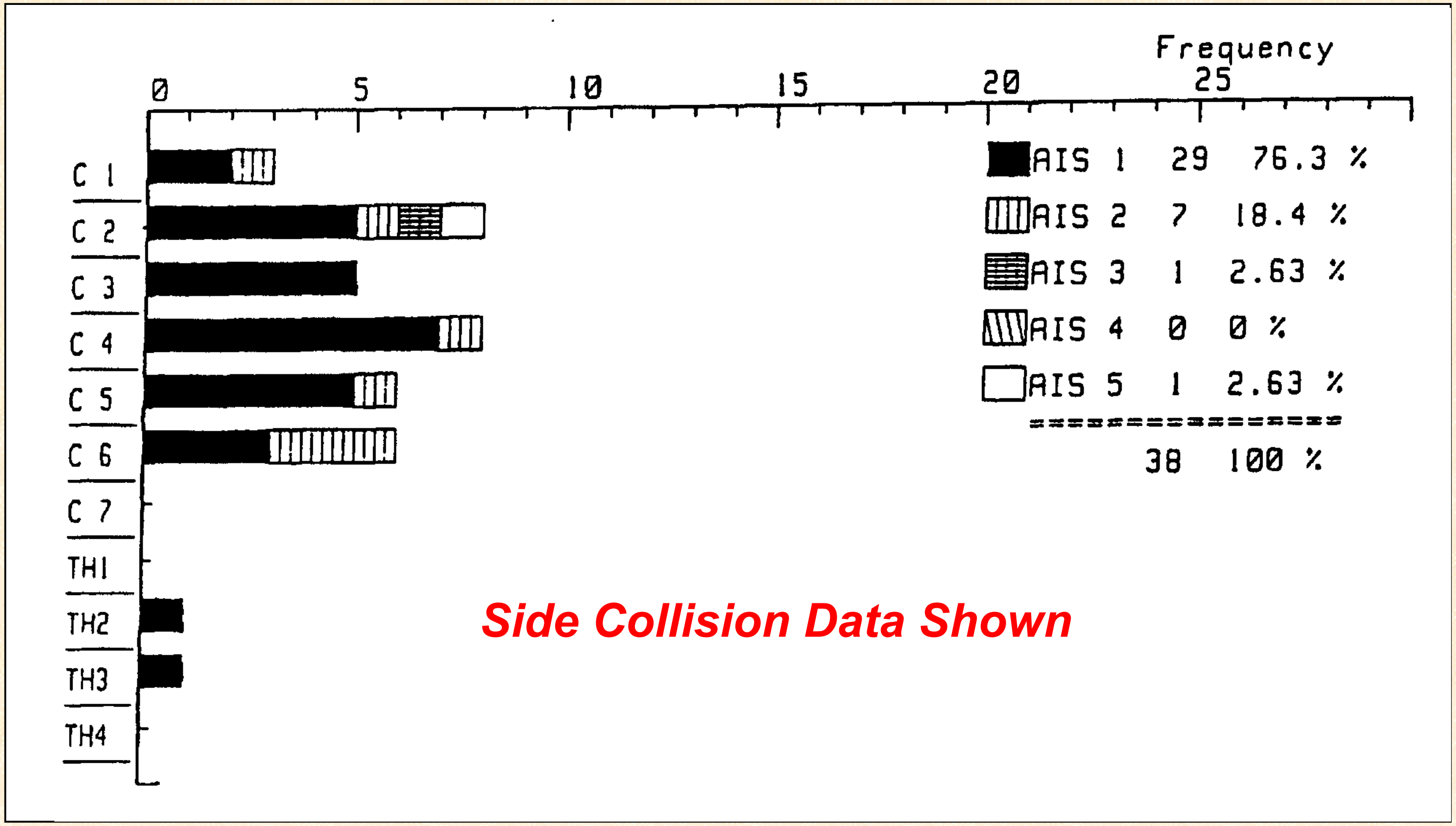
Considering far-side occupants, most experienced a cervical spine injury severity of AIS 1 (sprains) while one AIS 3 (fracture) and one AIS 5 (spinal cord laceration) were found.

The authors noted that the results show that AIS 1 injuries occur at an head/neck angle of 27 degrees for lateral collisions.

Ref. Kallieris, D., et al, SAE Technical Paper No. 912916, "Considerations for a Neck Injury Criteria", 1991.

Review of Automotive Impact Environment and Safety Research

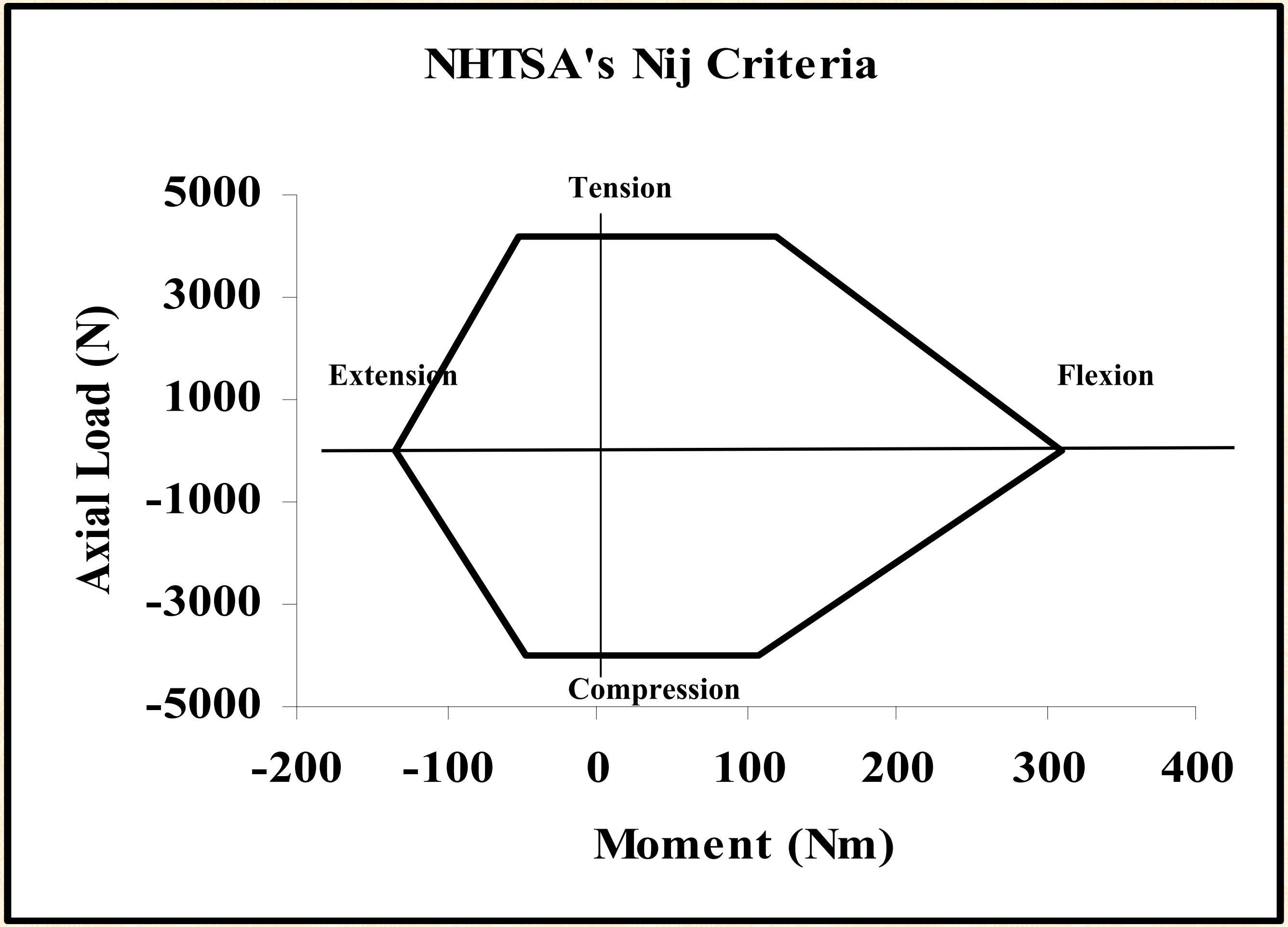
Other Studies supplement and/or confirm the aforementioned research activities



Location of the Vertical Column Injuries According to AIS Severity

Ref. Kallieris, D., et al, SAE Technical Paper No. 912916, "Considerations for a Neck Injury Criteria", 1991.

NHTSA’s Nij Injury Criteria for 50% Male for Neck Flexion and Extension



Conclusions

There are significant differences between the automobile and the aircraft impact environment and seating.

With few exceptions human tolerance neck injury evaluations were conducted at impact severity levels (velocity changes less than 22 ft/sec) that produce minor injuries.

The 22 ft/sec velocity change is consistent with the automobile side impact environment but it is less than the 44 ft/sec aircraft side facing seat impact environment.

Nevertheless the body of data indicates that the thresholds of neck injury may have been approached.

Candidate Neck Injury Criteria - Form #1

Considering all of the referenced and other reviewed data the following human candidate "kinematics based" neck injury criteria are proposed:

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

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 occur these limits are not to be exceeded up to the point of head contact. After head contact HIC not to exceed 1000.

Candidate Neck Injury Criteria - Form #2

Considering all of the referenced and other reviewed data the following human candidate "loads based" neck injury criteria are proposed:

Neck loads to be measured at the upper neck load cell:

$$Nij = (Fz/Fzc) + (Mx/Mxc) < 1.0$$

Where:

Fzc = 6806 N (1530 lbs) when Fz is tension
Fzc = 6160 n (1385 lbs) when Fz is compression
Mxc = 60 Nm (536 in-lbs)

Fz (tension limit) = 4170 N (940 lbs)
Fz (compression limit) = 4000 N (900 lbs)

Candidate Neck Injury Criteria - Form #2

Considering all of the referenced and other reviewed data the following human candidate "loads based" neck injury criteria are proposed: