Assessment of Head and Neck Injury Potential for Occupants of Typical Aircraft Seats and Interior Configurations During Forward Impacts

Presented to: The Fifth Triennial International Aviation Fire and Cabin Safety Research Conference

By: Richard DeWeese
FAA Civil Aerospace Medical Institute

Date: October 30, 2007

Background

- **Current aircraft seat dynamic qualification tests utilize the Head Injury Criteria (HIC) to evaluate head protection.**
  - Best available means of injury assessment when rule was adopted.
  - HIC of 1000 equates to a 16% to 43% chance of an AIS-3 injury (unconscious from 1-6 hours)
  - This level of injury means that occupants may not be alert and able to assist with their own evacuation after a crash.

Background

- **Current aircraft seat qualification tests do not assess neck injury potential.**
  - HIC reduction methods could have the unintended consequences of inducing injuries to the neck.
  - Technology and injury criteria are now available to assess neck injuries.

Purpose

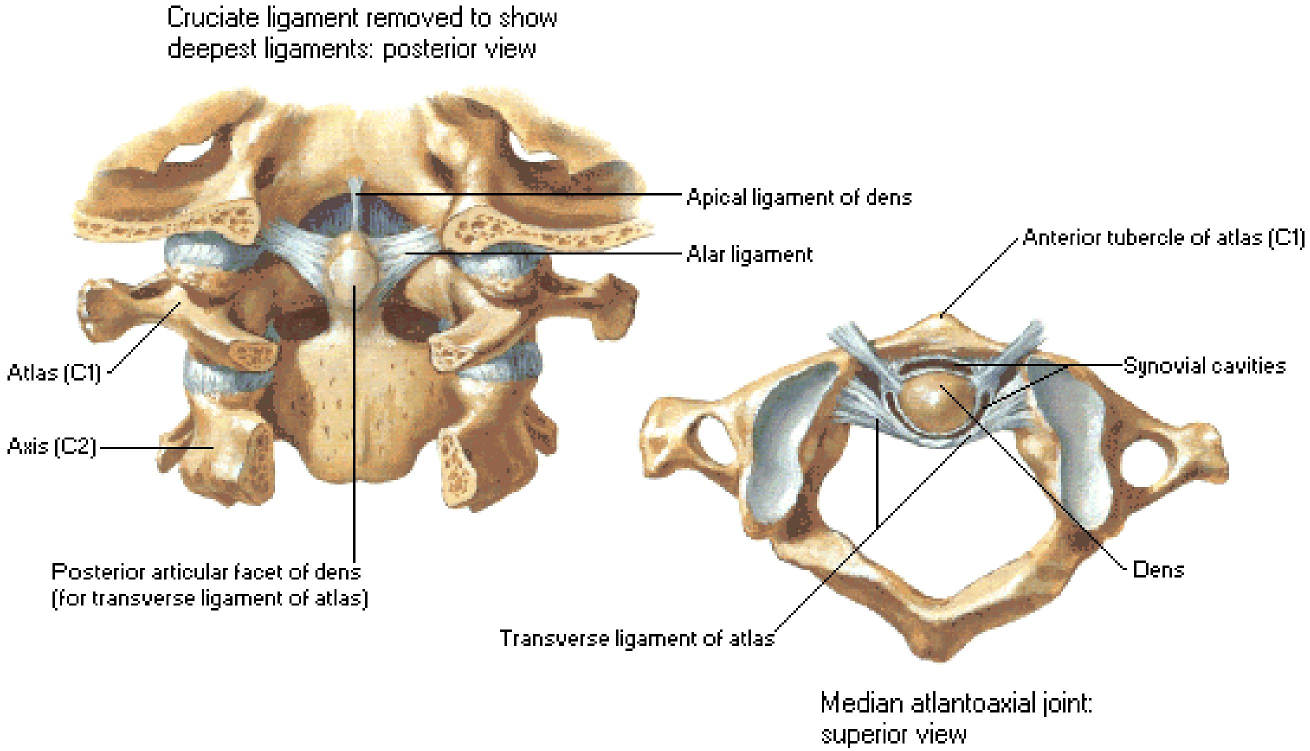
- **Use state-of-the-art techniques to evaluate the potential for head and neck injury for occupants of typical aircraft seat configurations during forward impacts**
  - Selected configurations are those with greatest perceived risk of injury.
  - Configurations to be representative of those that would meet current Head Injury Criteria.

Neck Injury Assessment Technique

- **Federal Motor Vehicle Safety Standard 208 requires evaluation of neck injury potential during new vehicle assessments.**
  - Injury Criteria cited are applicable to aircraft occupants (people are people).
  - Can be assessed using Hybrid-III ATD (an approved version is available for aviation use).

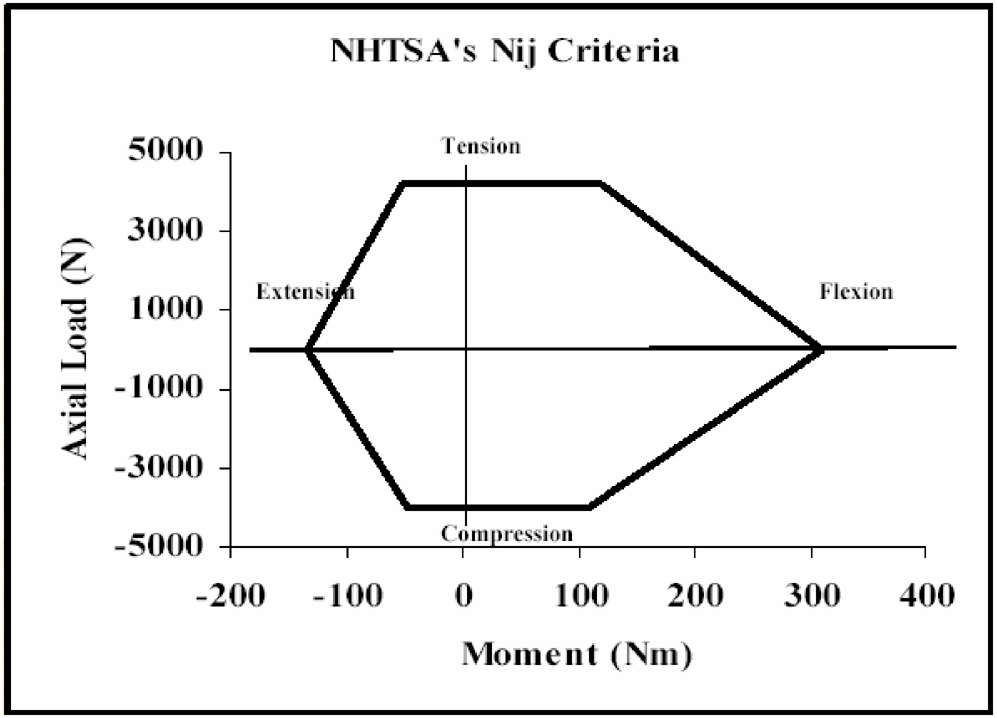
Neck Injury Assessment Technique

- **Nij Criteria**
  - Accounts for Complex Neck Anatomy



Neck Injury Assessment Technique

- **Nij Criteria**
  - Combines axial loading and bending moment at the top of the neck (occipital condoyle location)



Neck Injury Assessment Technique

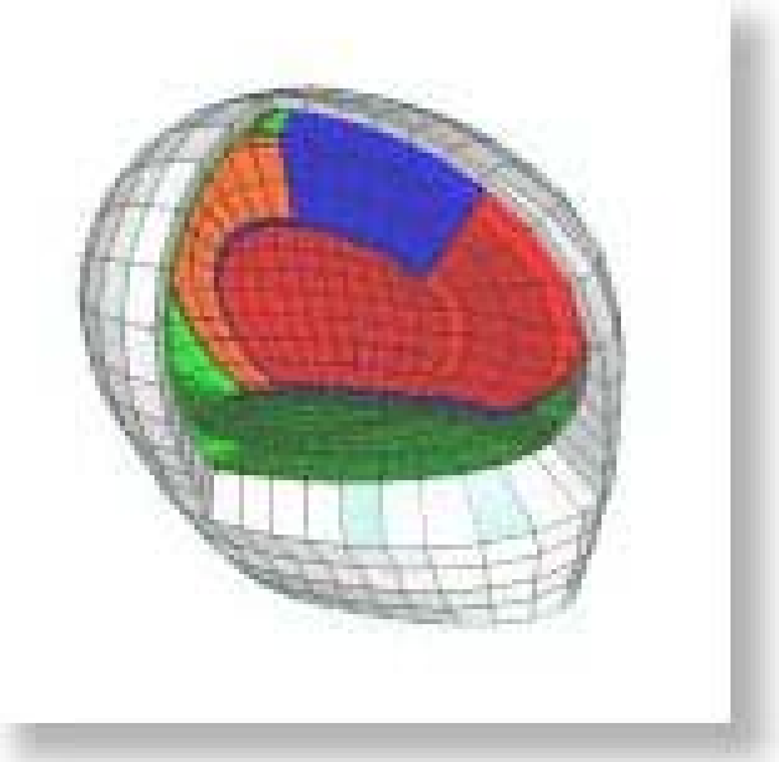
- **Nij Criteria**
  - Formula:

$$N_{ij} = \frac{F_z}{F_{zc}} + \frac{M_y}{M_{yc}}$$

  - Intercepts for 50% Male ATD
    - Fzc Tension = 1530 lb
    - Fzc Compression = 1385 lb
    - Myc Flexion = 2748 in-lb
    - Myc Extension = 1200 in-lb
- **Tension and Compression also limited**
    - Tension = 937 lb   Compression = 899 lb

Head Injury Assessment Technique

- **SIMon (Simulated Injury Monitor) Finite Element Head Model**



Head Injury Assessment Technique

- **SIMon Finite Element Head Model developed by National Highway Traffic Safety Administration (NHTSA) is available for use by researchers.**
  - Model consists of a rigid skull, dura-CF layer, the brain, the falx cerebri, and the bridging veins.
  - Model validated using human cadaver and animal tests.
- **Software can be executed on a high-end PC.**
- **Software is FREE !**

Head Injury Assessment Technique

- **The SIMon head model permits independent assessment of injury mechanisms.**
  - Diffuse Axonal Injury
    - Injury related to strain of neural-fibers.
    - Debilitation related to both the degree of strain and the volume of the brain that experienced the strain.
    - Injury is a cumulative effect during the impact.
    - Predicted by the Cumulative Strain Damage Measure (CSDM).
    - 50% probability of Diffuse Axonal Injury corresponds to a CSDM value of 55% at a strain level of 0.15.

Head Injury Assessment Technique

- **The SIMon head model permits independent assessment of injury mechanisms.**
  - Contusion
    - Injury related to negative pressure created by high stresses in brain tissue.
    - Countre-coup type of injury.
    - Injury is a cumulative effect during impact.
    - Predicted by Dilatation Damage Measure (DDM).
    - 50% probability of Contusions corresponds to a DDM value of 7.2%.

Head Injury Assessment Technique

- **The SIMon head model permits independent assessment of injury mechanisms.**
  - Acute Subdural Hematoma
    - Injury related to relative motion between the brain and the skull.
    - Relative motion strains (and disrupts) blood vessels
    - Injury level related to peak strain
    - Predicted by Relative Motion Damage Monitor (RMDM)
    - 50% probability of Acute Subdural Hematoma corresponds to a RMDM value of 1.0

Head Injury Assessment Technique

- **Angular Acceleration and Velocity**
  - Found in some cases to be useful as global predictors of brain injury.
  - Required input (along with linear accelerations) for finite element head models.
  - Measurement during sled tests not straight forward, requiring specialized instrumentation and data analysis techniques.

Head Injury Assessment Technique

- **Skull Fracture Correlate (SFC)**
  - Developed by NHTSA and Medical College of Wisconsin.
  - HIC-type calculation that correlates better to fracture than any of the standard HIC formulations.
  - Average acceleration during the HIC 15 interval.
  - 15% probability of skull fracture corresponds to a SFC value of 120 G.

Test Protocol

- **Typical seating configurations found in both transport and general aviation chosen for study.**
  - Choices based on highest likelihood of head and / or neck injury.
- **Rigid seat used to control variability.**
- **Tests conducted without yaw to reduce variability and simplify analysis of results.**
- **Some tests repeated to assess data spread.**

Test Protocol

- **Non-Contact Test Configurations**
  - 4-Point restrained occupant subjected to 26 G forward deceleration.
  - Lap belt restrained occupant subjected to a 16 G forward deceleration.

Test Protocol

- **Head Impact Test Configurations**
  - Lap belt restrained occupant impacting an economy-class seat back.
    - Seat back designed to limit head injury.
  - Lap belt restrained occupant impacting a wall.
    - Wall made from 1” thick nomex honeycomb panel supported at the top and bottom.
    - Intended to emulate the stiffness of a class divider panel.

Test Protocol

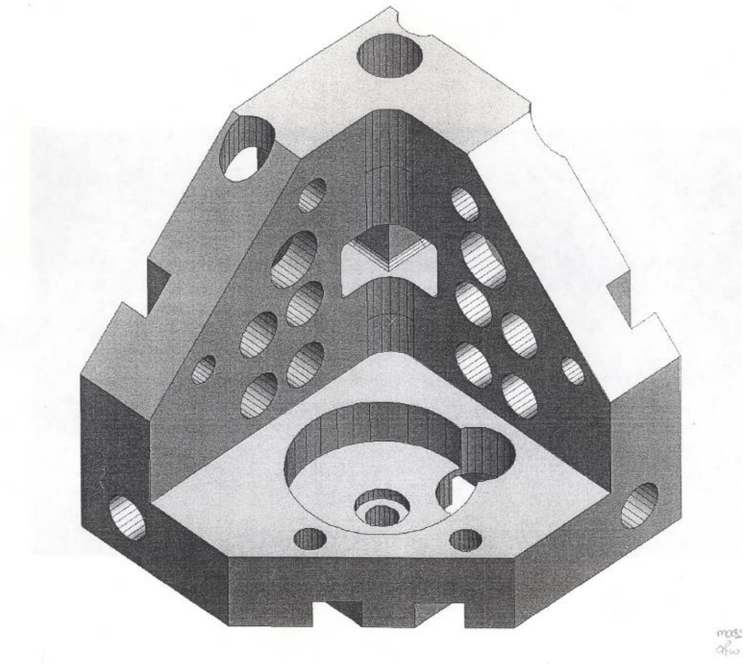
- **Side-Facing Seat Configurations:**
  - Assessment of head and neck injury included as part of a project to evaluate the ES-2 side-impact dummy.
  - 3-point restrained occupant subjected to a 16 G lateral deceleration.
    - Seated in center position
    - Seated next to a rigid wall
    - Seated next to an armrest
    - Inflatable torso restraint also evaluated with each configuration

Test Protocol

- **FAA Hybrid-III and ES-2 ATD's used with specialized instrumentation**
  - Upper- and lower-neck load cells to directly measure neck loads.
  - A nine-accelerometer array and computational algorithm to gather angular head acceleration data was provided by TNO (a research firm from the Netherlands)

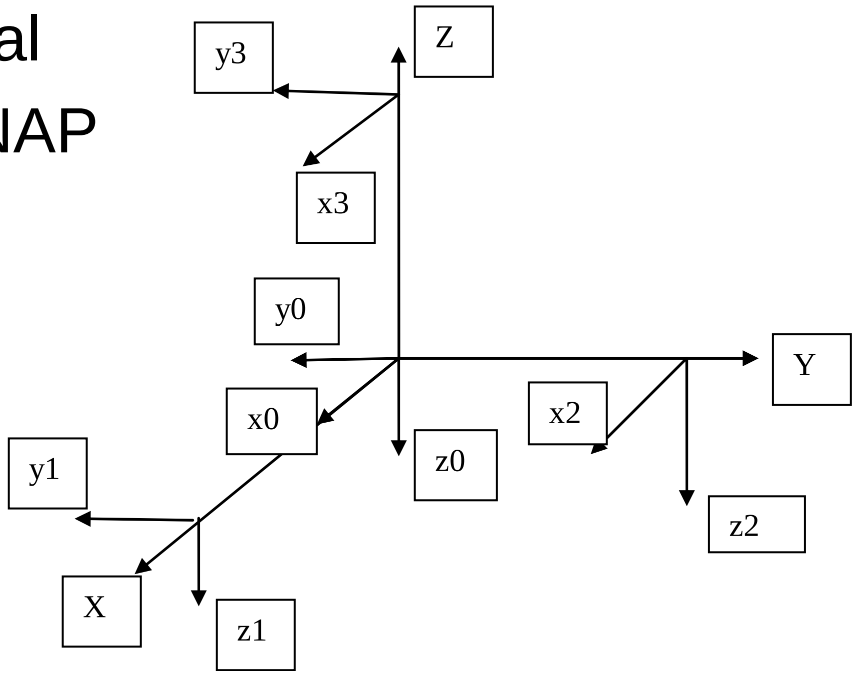
Test Protocol

- **FAA Hybrid-III and ES-2 ATD's used with specialized instrumentation**
  - TNO Nine Accelerometer Package (NAP)
    - Designed to reduce resonant responses and location inaccuracies found in some other NAP arrangements.
    - Fits both the Hybrid III and ES-2 head.



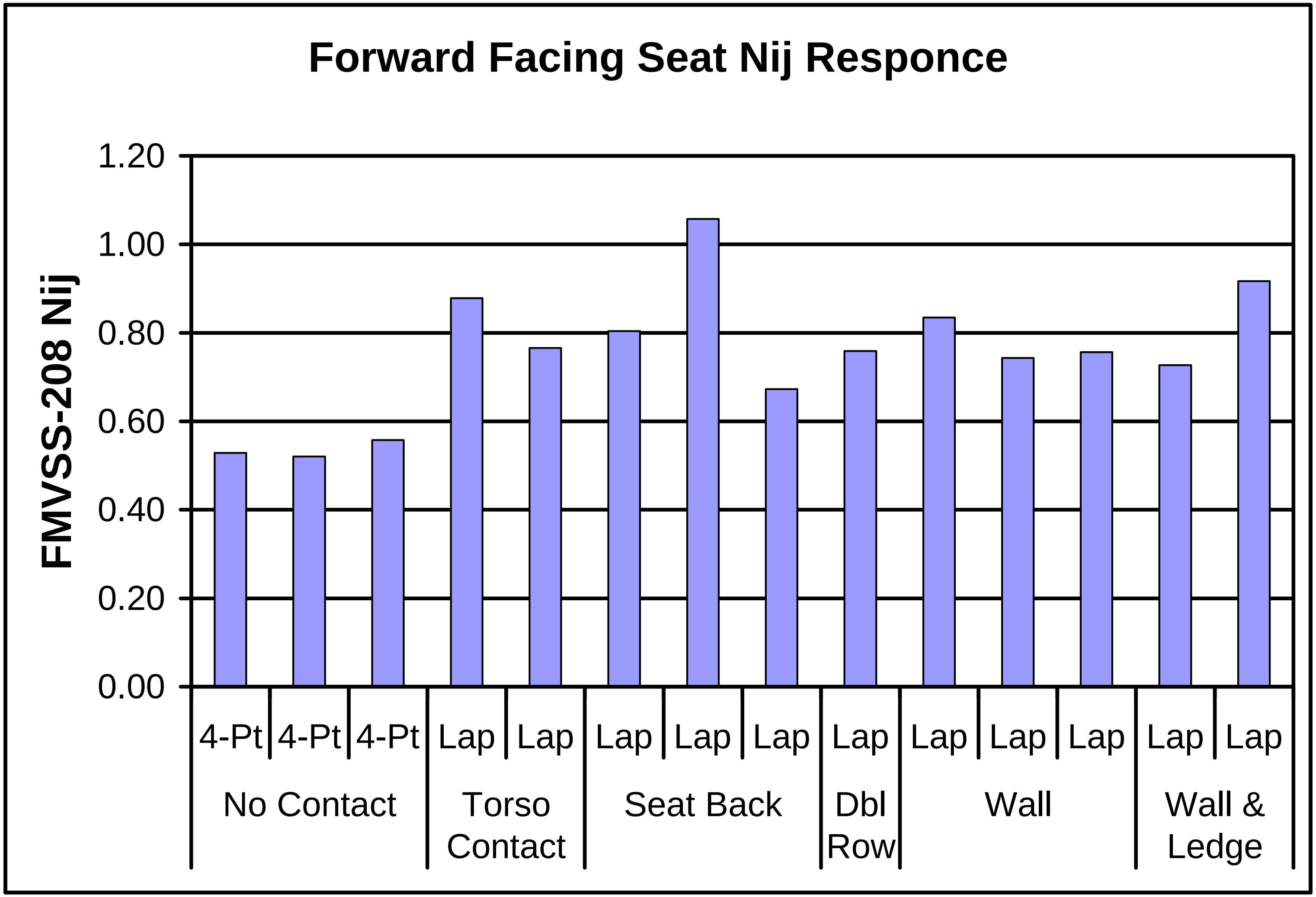
Test Protocol

- **FAA Hybrid-III and ES-2 ATD's used with specialized instrumentation**
  - Angular acceleration derived using measured differential linear accelerations and NAP geometry.
  - Computational algorithm implemented in Matlab.

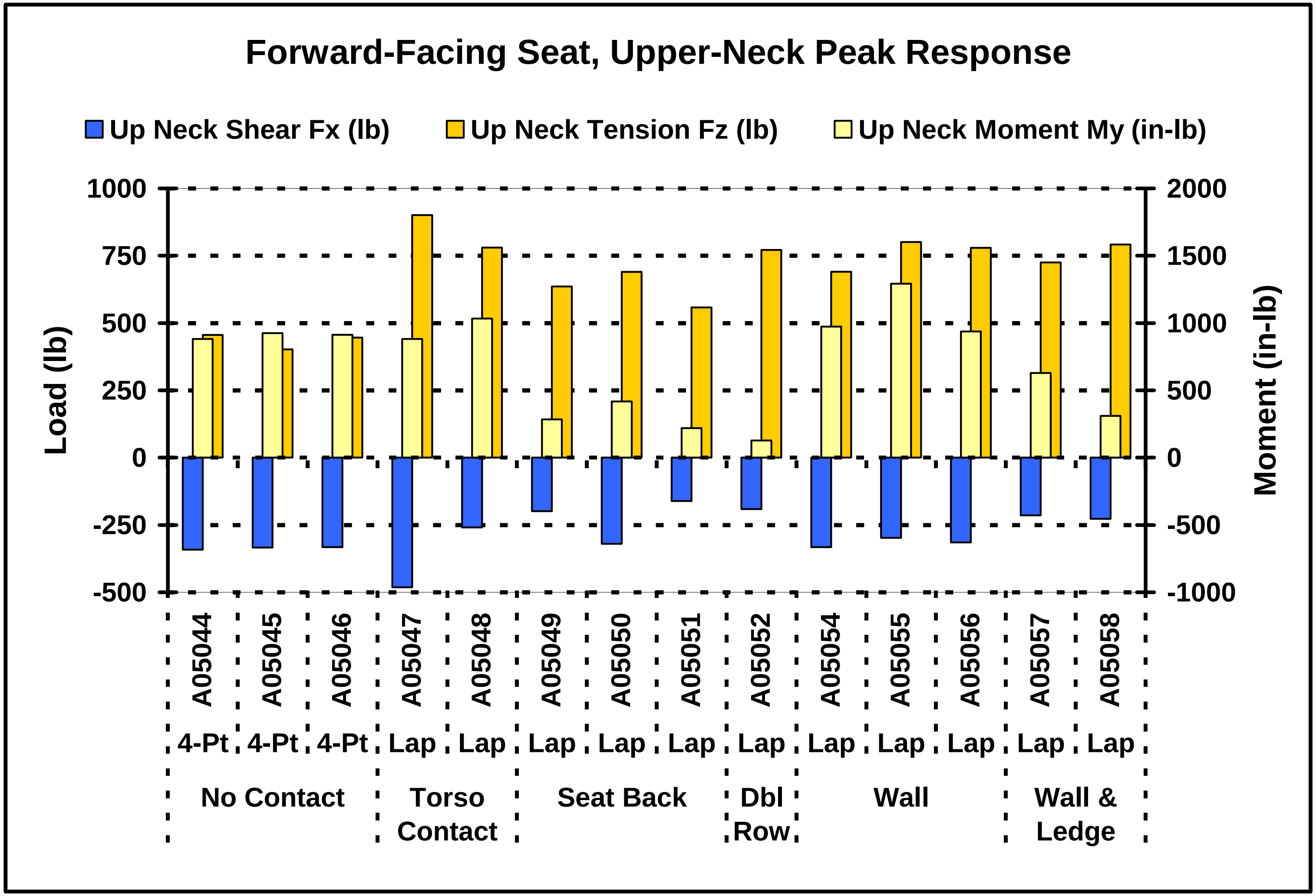


Typical Sled Test

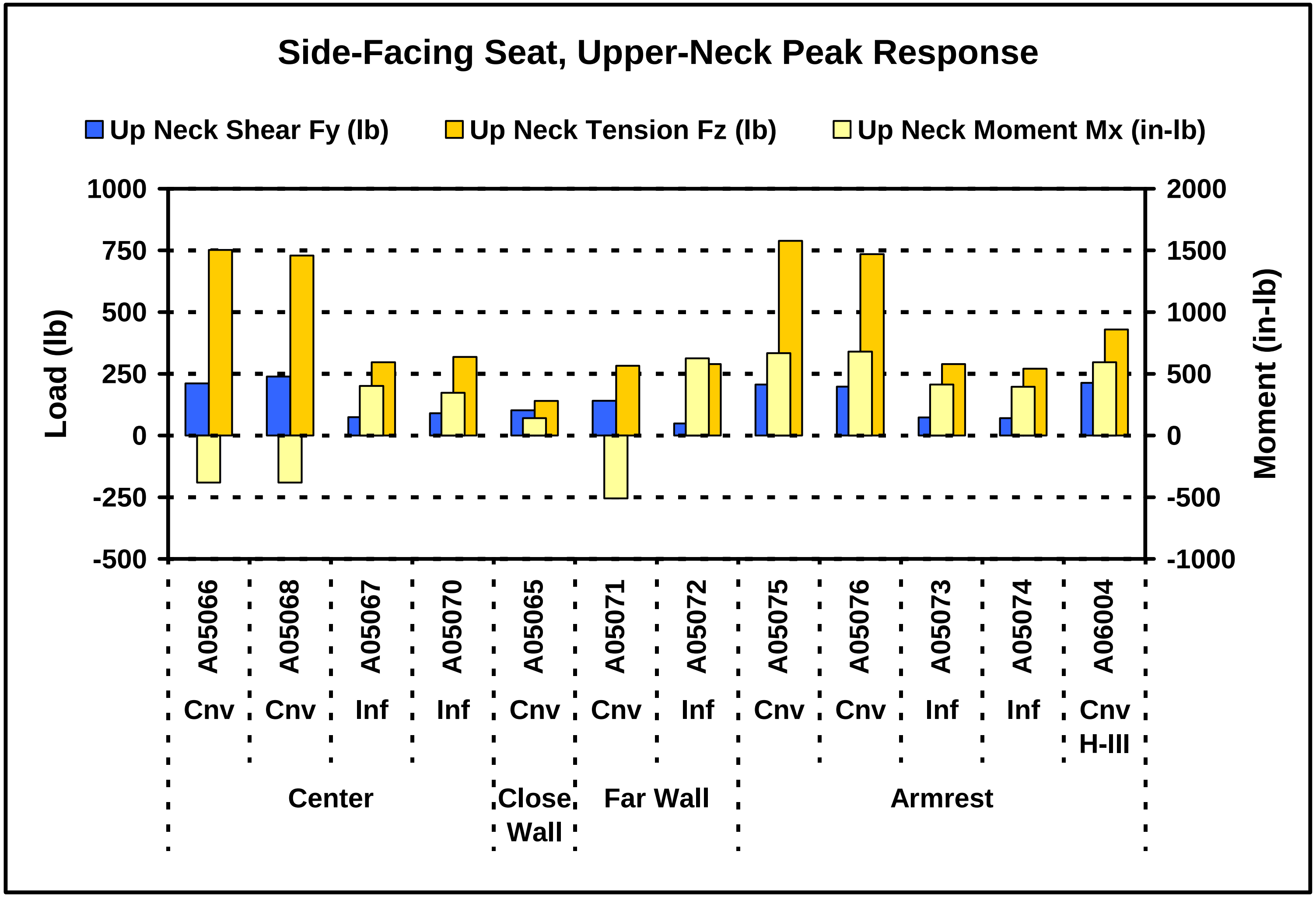
Neck Injury Assessment



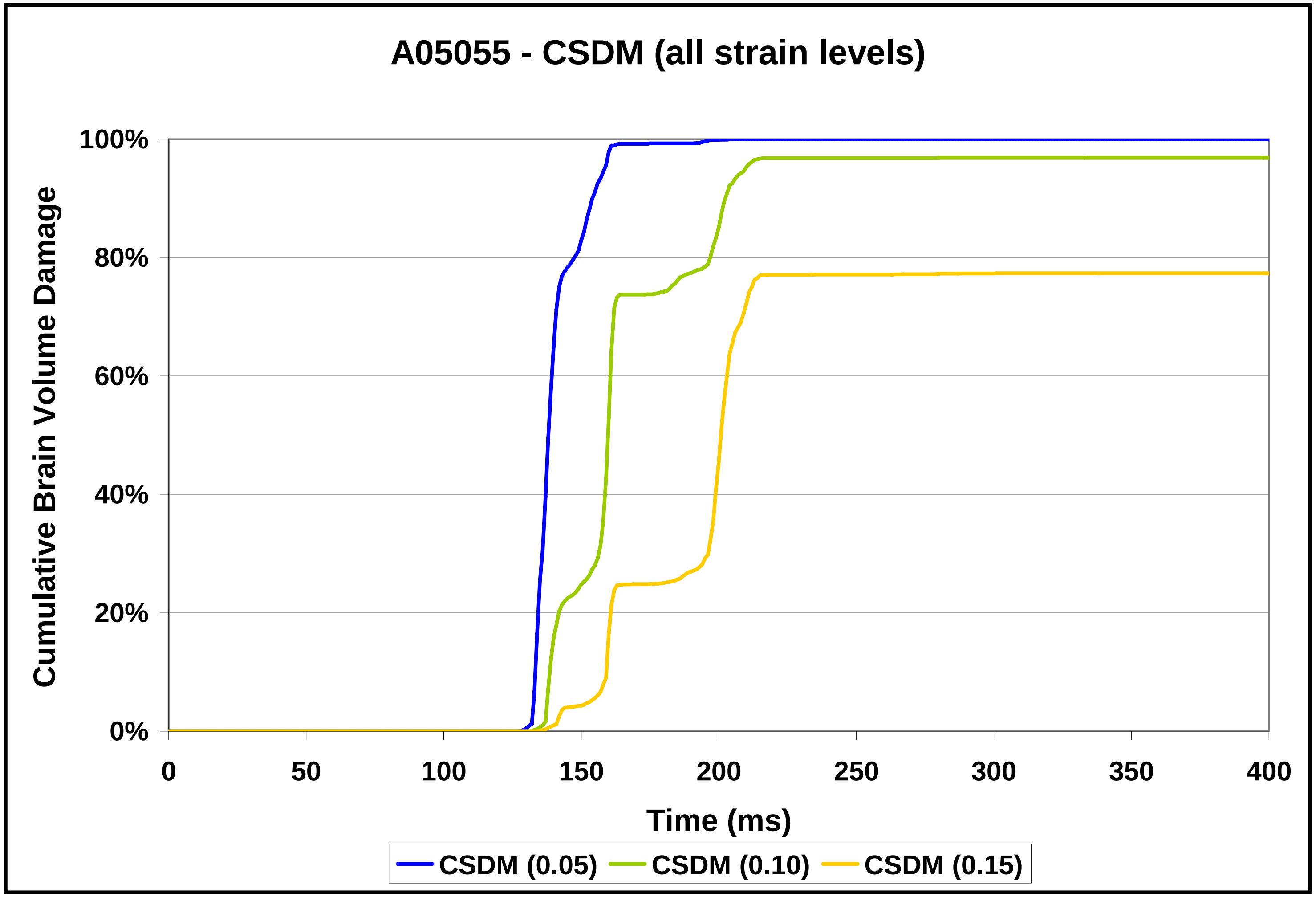
Neck Injury Assessment



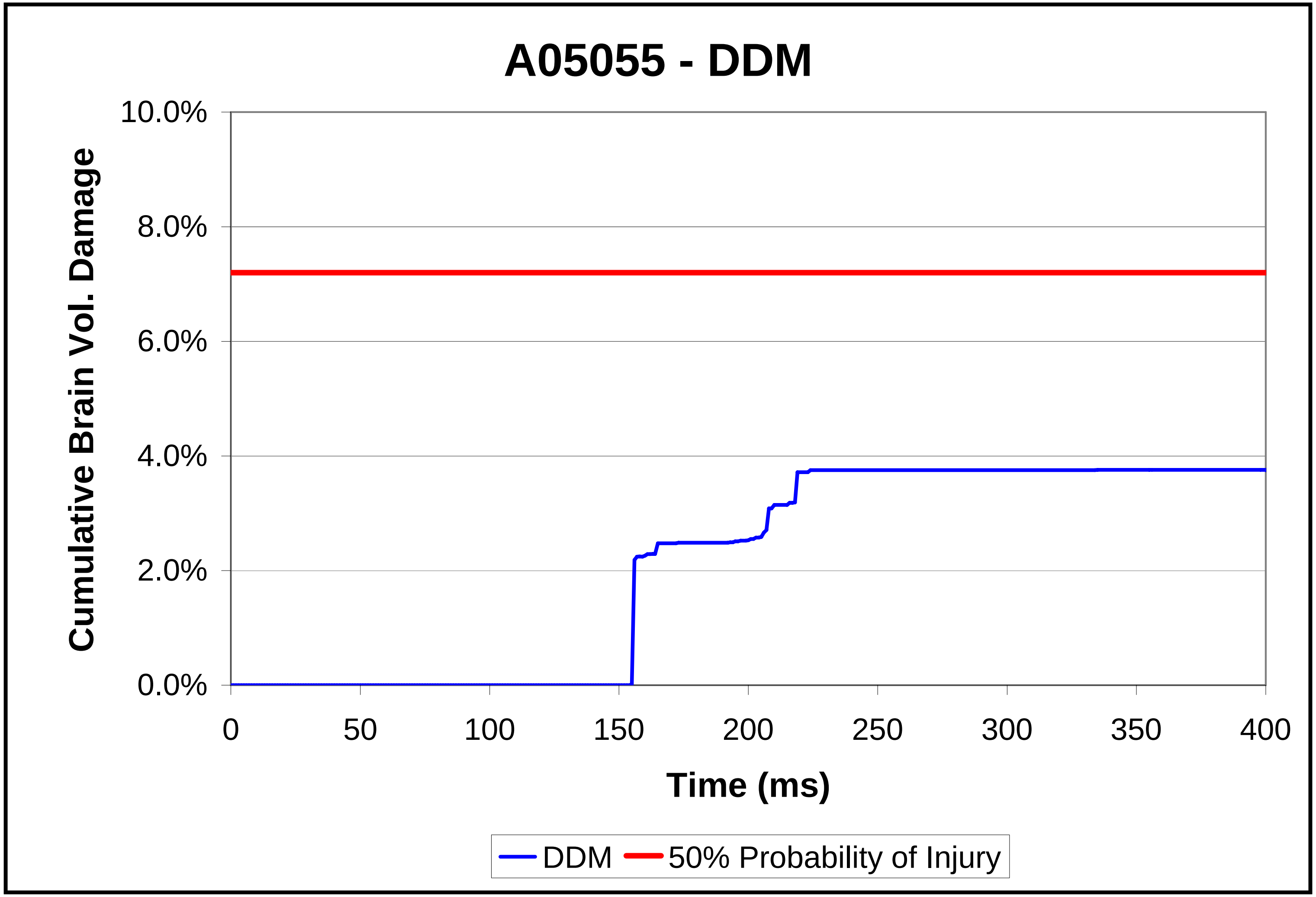
Neck Injury Assessment



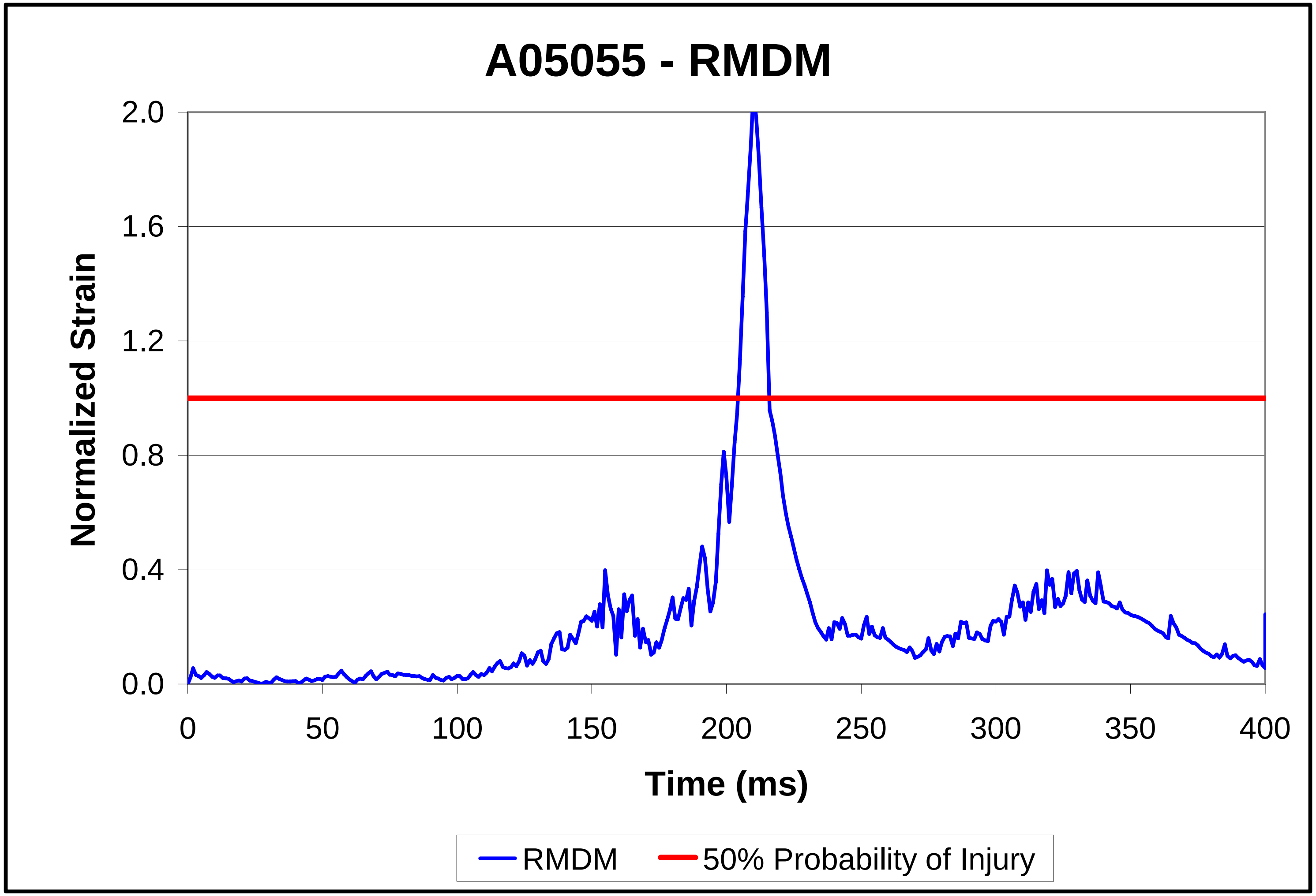
Head Injury Assessment



Head Injury Assessment



Head Injury Assessment



Head Injury Assessment

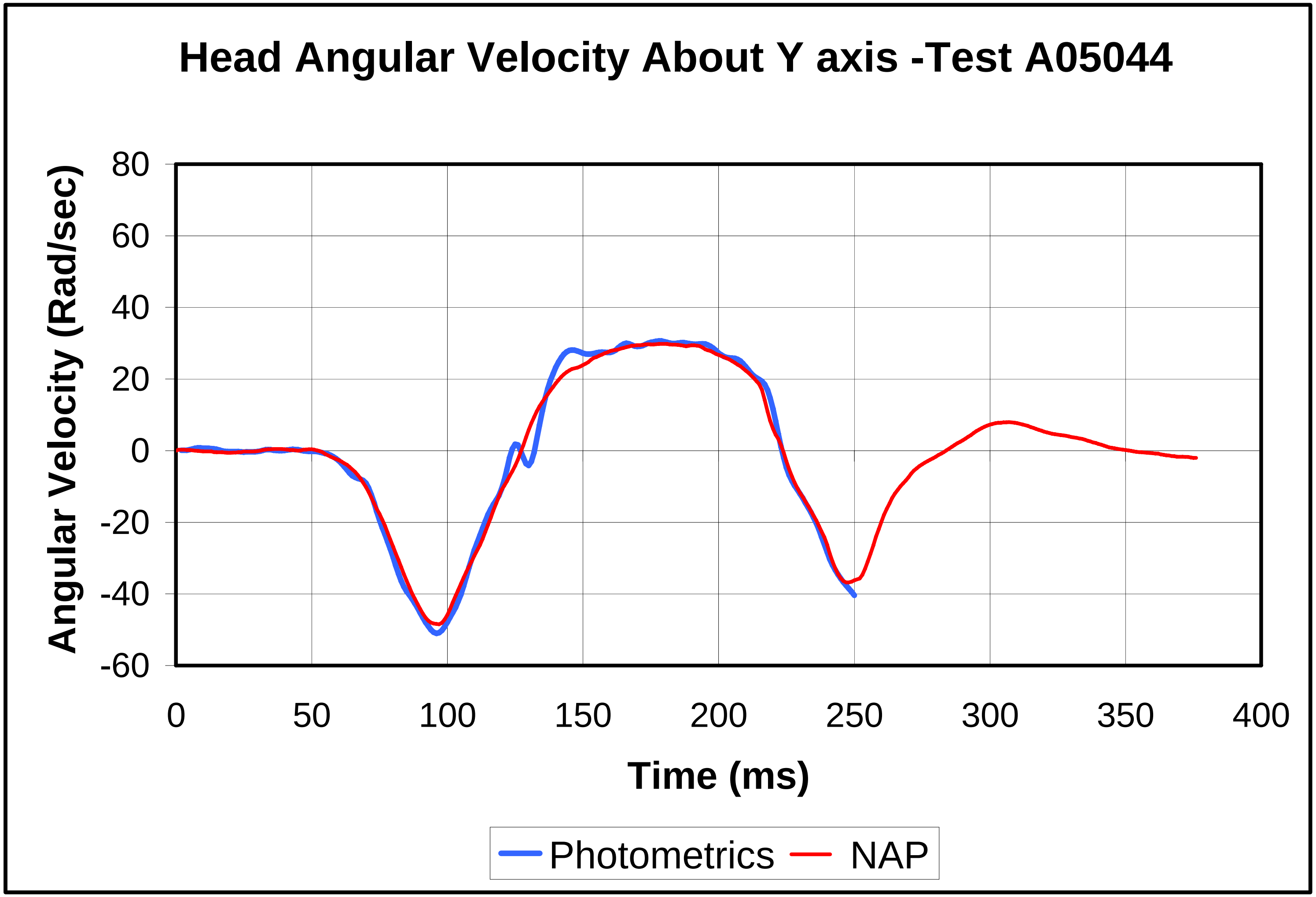
Test Configuration	Limit	No Contact	Seat Back	Wall	Side Facing
Restraint		4-Pt	Lap	Lap	3-Pt
Test Number		A05044	A05050	A05055	A05076
Impact Vel (ft/s)		42.2	44.4	44.3	45.1
Impact Acc (g)		-26.0	-16.6	-16.3	-16.5
HIC Unlimited	1000	467	1432	2058	1161
HIC after contact	1000	0	1350	1623	298
HIC15	700	206	1114	802	614
Head Max Resultant XYZ Accel		52.6	120.7	138.0	122.2
Head Positive Angular Accel (NAP)	2780	2515	10675	6824	3127
Head Negative Angular Accel (NAP)	2780	-3154	-4981	-3765	-4648
Head Positive Angular Vel (NAP)		30	22	39	31
Head Negative Angular Vel (NAP)		-48	-51	-66	-83
CSDM (.05)		0.96	1.00	1.00	1.00
CSDM (.10)		0.54	0.87	0.97	0.89
CSDM (.15)	0.55	0.10	0.54	0.77	0.48
DDM	0.072	0.00	0.06	0.04	0.01
RMDM	1	0.41	1.10	2.07	1.72
SFC	130	45.2	88.6	77.3	69.9

Technical Lessons Learned

- **Angular Acceleration derivation not straightforward.**
  – Difference routines in the NAP algorithm multiply errors. Some sources of error are:
    - Relatively high noise floor of 12 bit A/D in data acquisition system used.
    - Excessive cross-axis sensitivity of some accelerometers used.

  – Errors compensated for by setting boundary conditions and comparing results with photometric analysis results.

Technical Lessons Learned



Technical Lessons Learned

- **Angular velocities derived using photometric analysis correlated well to values derived using the NAP technology (for those test conditions where the head motion was planar).**

- **Preliminary assessments of brain injury may be made for simple impact scenarios (where the head motion is primarily planar) by combining conventional head CG acceleration data with photometrically derived angular velocity data.**

Conclusions

- **Neck injury was not a significant risk in most of the forward facing configurations tested.**
  - Nij exceed FMVSS 208 limit in only one case (however, the HIC was over the limit as well).
  - Peak tension and compression values not exceeded in any of the cases.
- **The injury potential, represented by the lateral neck forces/moments measured, is not currently well defined.**
  - Research is ongoing to define appropriate lateral neck injury criteria.

Conclusions

- **For those test conditions where HIC was greater than 1000, at least one of the brain injury parameter limits were also exceeded.**

- **While the current study evaluated, single impacts, the cumulative nature of some brain injury mechanisms indicates that multiple head impacts occurring during a typical seat dynamic test should be considered as one event from a HIC evaluation standpoint.**

Conclusions

- Research is ongoing to better understand the mechanisms of concussive injuries and their affect on loss of consciousness.

- Application of this new understanding may allow the expected level of alertness after an impact to be quantified using global parameters such a angular acceleration or discrete measures provided by models such as SIMon.

Acknowledgments

- **Co-authors:**
  - David Moorcroft, CAMI
  - Mat Phlippens, TNO Netherlands

- **Software Support:**
  - Erik Takhounts at NHTSA supplied the SIMon software and assisted us implementing it.

- **Test Articles:**
  - Weber Aircraft supplied the test seats
  - U.S. Army supplied the 4-point restraint systems

References

- DeWeese R, Moorcroft D, Green T, Philippens M.M.G.M. Assessment of Injury Potential in Aircraft Side-Facing Seats Using the ES-2 Anthropomorphic Test Dummy. Washington DC: Federal Aviation Administration May 2007; Report No. DOT/FAA/AM-07/13.