# Modeling of Dynamic Responses and Injury Potentials to Occupants on Sidefacing Aircraft Seats

**Hamid Lankarani**

***National Institute for Aviation Research***
***Wichita State University, USA***

***Fourth Aircraft Fire and Cabin Safety Research Conference***
***Lisbon, Portugal***
***November 15-18, 2004***

# Problem Statement

**Business Jet Customers Demand Unique Interiors**

**... including Side-Facing Divans**

# Problem Statement

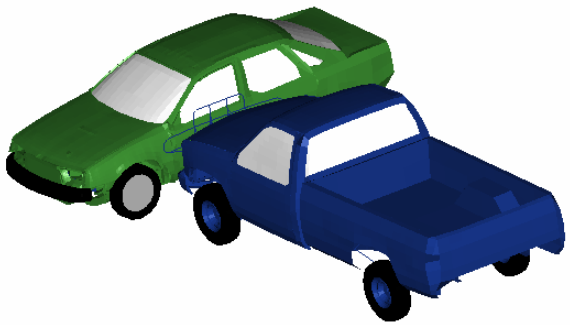
- Passengers seated on side-facing seats (**SFS**) experience different dynamic response compared to those on forward or aft-facing seats in the event of a crash.
- Certification of the SFS has become mandatory under FAR 25.785, " … a side-facing seat must provide equivalent level of occupant protection as a forward or aft-facing seats with a safety belt and shoulder harness, and in general provide the protection provisions of 25.562."
- AC25.562 does not specify a method of compliance nor the injury-pass/fail criteria for SFS's, but suggests the use of ***injury criteria*** and ***side impact dummies*** or ATD's from the automotive industry.

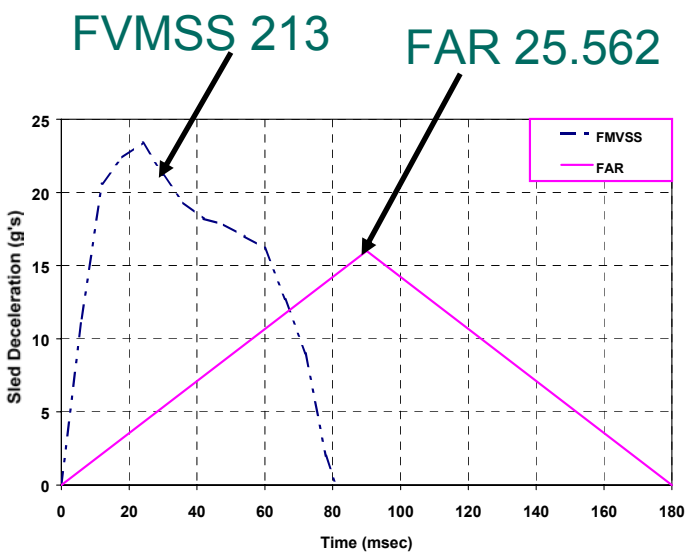
# Objectives

- Investigate potential injuries corresponding to single and multiple-occupant (divan-type) SFS configurations.
- Through modeling, identify potential configuration(s) that provide highest level of occupant protection.
- Identify appropriate injury criteria and ATD related to SFS certification.
- Conduct a parametric study and evaluate the potential of neck injuries utilizing the early proposed neck injury criteria

# Aircraft vs. Automotive Side Impact

- No structure intrudes the side of occupant(s).
- Nature of occupant-to-occupant contact is different.
- Occupants are exposed to much slower rate of chest and rib compression, but for a longer period.
- Impact severity
  - FMVSS-213 - 24G in 80 ms
  - FAR-25.562 - 16G in 180 ms





# Side Impact ATD's

DOT SID

EuroSID

BioSID

# Injury Criteria

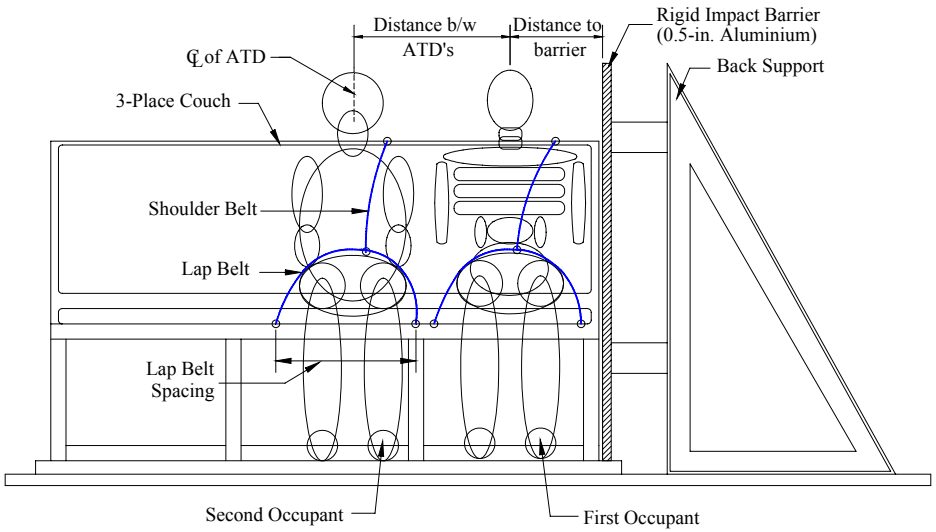
- FMVSS 214 Criteria
  - Lateral acceleration of the Pelvis < **130G**
  - Thoracic Trauma Index TTI(d) < **85G**
- Draft ECE 95 Criteria (for EuroSID and BioSID tests only)
  - Viscous Criteria (V*C) < **1 m/s**
  - Rib deflection < **42 mm**
- Research criteria
  - Pubic symphysis forces < **10 KN (2,250 lb)**
  - Lateral abdominal forces < **2.5 KN (550 lb)**
  - Lateral neck moments < **40 N.m (350 lb-in)**
  - Lateral neck forces < **1.1 KN (250 lb)**

# Injury Criteria

- Criteria in FAR's
  - Head Injury Criteria (HIC)< **1000**
  - Compressive lumbar load < **1,500 lb**
  - Femur load < **2,250 lb** (for Part 25 only)
  - Shoulder strap load < **1,750 lb** (per strap)
  - Restraint retention : upper torso restraint strap must remain on the occupant's shoulder during the impact.
  - Submarining : lap safety belt must remain on the occupant pelvis during the impact, and no submarining is allowed.

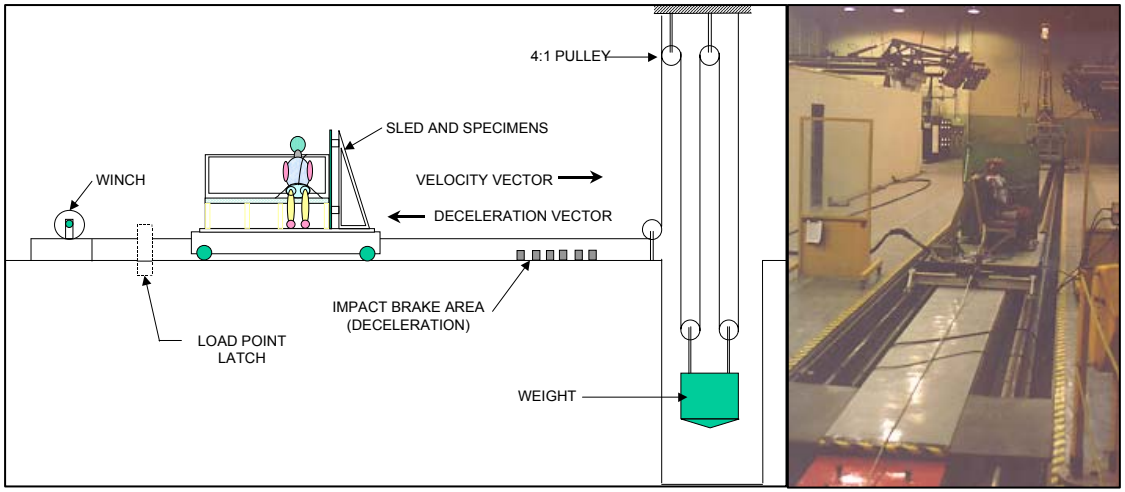
# Dynamic Sled Tests

- Test Fixtures
  - Steel, 3-place couch with no energy absorbing features
  - Rigid barrier to maximize the potential for the injury

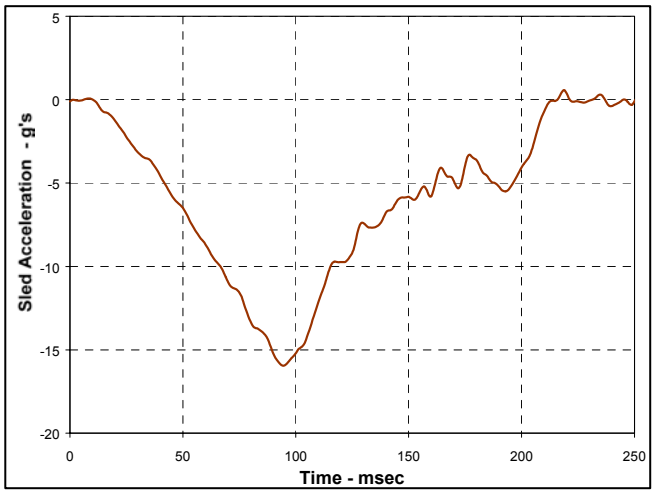



- Restraint System
  - 3-point polyester restraint system with lap belt and shoulder harness
- ATD's
  - Single occupant seating configurations
    - SID, EuroSID and BioSID ATD's
  - Multi-occupant seating configurations
    - Hybrid II as the second ATD

# Test Conditions for FAR 25.562 - Type 2




CAMI Sled Test Facility




Typical Deceleration Pulse

- 0° yaw for the seat relative to the sled axis
- Sled impact velocity - 44 ft/s
- Triangular pulse
  - Peak acceleration - 16G
  - Time Rise - 90 ms

# SFS Tests with SID

- Evaluate
  - Effect of ATD spacing and belt configuration on
    - Pelvic acceleration and TTI
- Test Configurations
  - Single occupant tests with SID
  - Multiple-occupant tests with
    - SID sitting next to the barrier
    - Hybrid II sitting next to the barrier

# Sample of Single Occupant Tests with SID

**Distance to barrier - 15 in.**

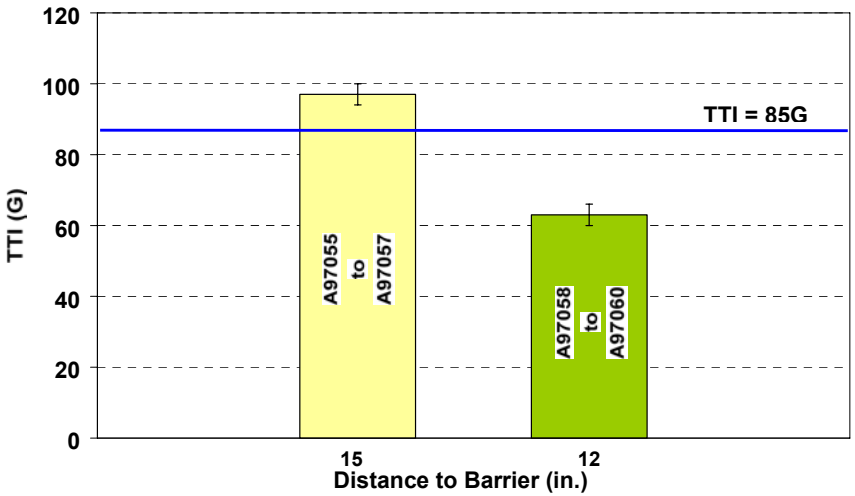
- 90-in. couch
- TTI - 94 G
- Max. Pelv. Acc. - 93 G
- HIC - 1872

**Distance to barrier - 12 in.**

- 72-in. couch
- TTI - 60 G
- Max. Pelv. Acc. - 87 G
- HIC - 1825

**TTI and pelvic acceleration are functions of distance to barrier**

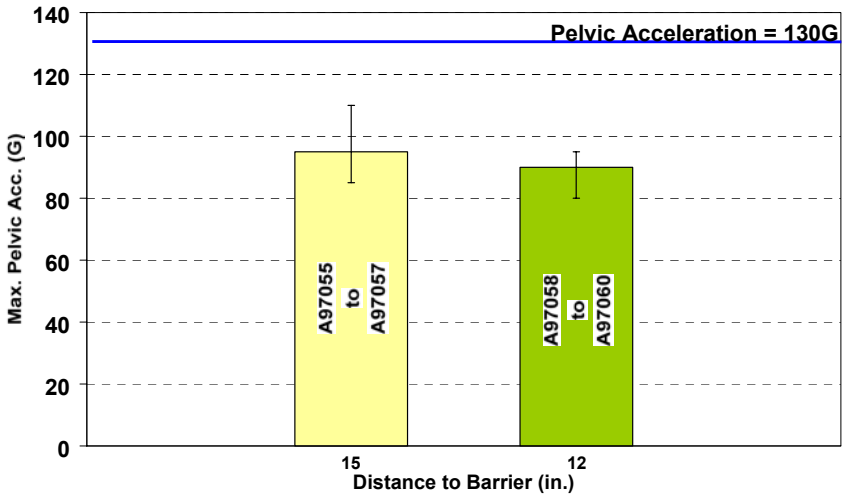
# Variation of TTI and Pelvic Acceleration for SID




- Single occupant
- ATD distance to barrier - 15 in.
- Lap belt spacing - 30 in.

- Single occupant
- ATD distance to barrier - 12 in.
- Lap belt spacing - 24 in.

TTI




- Single occupant
- ATD distance to barrier - 15 in.
- Lap belt spacing - 30 in.

- Single occupant
- ATD distance to barrier - 12 in.
- Lap belt spacing - 24 in.

Pelvic Acceleration

**For barrier to ATD centerline distance of**

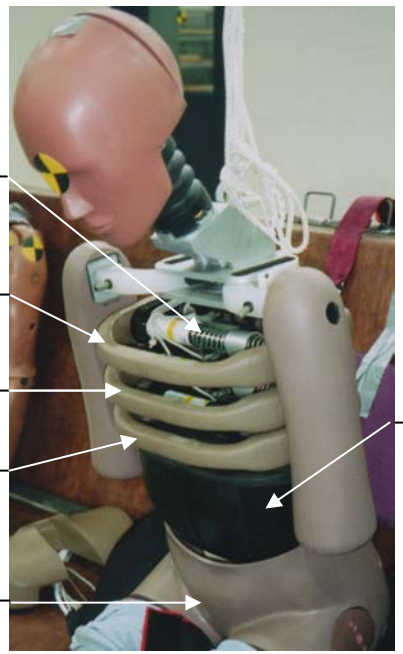
- **12-in. –> TTI and Pelvic Acceleration are below threshold**

# Summary Results of SID Tests

| CAMI Test # | ATD Type & Order | Distance to Barrier (in.) | Distance Between ATDs (in.) | Lap Belt Spacing (in.) | Max Pelvic Accel. (G's) | TTI (G's) | HIC |
|---|---|---|---|---|---|---|---|
| A96107 | SID | 15.75 | n/a | 20.5 | 101 | 95 | -- |
| A96108 | SID & HII | 15.75 | 19 | 20.5,20.5 | 134 | 107 | -- |
| A96123 | SID | 15.75 | n/a | 20.5 | -- | 72 | -- |
| A97055 | SID | 15 | n/a | 30 | 92.7 | 93.5 | 1872 |
| A97056 | SID | 15 | n/a | 30 | 84.1 | 96.9 | 1851 |
| A97057 | SID | 15 | n/a | 30 | 108.5 | 99.7 | 2206 |
| A97058 | SID | 12 | n/a | 24 | 87.3 | 60.6 | 1825 |
| A97059 | SID | 12 | n/a | 24 | 94.9 | 62.9 | 1957 |
| A97060 | SID | 12 | n/a | 24 | 80.8 | 67.8 | 2196 |
| A97061 | SID & HII | 12 | 24 | 24,24 | 89.8 | 62.2 | 1433 |
| A97062 | SID & HII | 12 | 18 | 21,21 | 93.1 | 64.1 | 1442 |
| A97063 | SID & HII | 12 | 18 | 21,21 | 86.8 | 68.5 | 1711 |
| A97064 | SID & HII | 9 | 18 | 18,18 | 35.3 | 32.9 | 1451 |
| A97065 | HII & SID | 9 | 21 | 18,24 | 47.5, 53.3 | --, 61.4 | --, 1916 |
| A97066 | HII & SID | 9 | 24 | 18,30 | 48.9, 68.5 | --, 79.1 | 300, 1061 |
| A97067 | HII & SID | 12 | 24 | 24,24 | 107, 54.9 | --, 103.9 | 1840, 4252 |

# SFS Tests with EuroSID-1

- EuroSID-1 provides data on:
  - Rib deflection data to compute the Viscous Criteria (V*C)
    - The ATD has three rib deflection potentiometers
  - Pubic force compression load
  - Lateral abdominal force



# Sample of EuroSID-1 Tests with Single Occupant Seating

**Distance to barrier - 15.75 in.**

**72-in couch**

## Padded Wall

- Max. pelv. acc. - 105 G
- TTI - 65 G
- V*C - 0.74 m/s
- Rib deflections
  - Upper Rib - 45.0 mm
  - Middle Rib - 39.9 mm
  - Lower Rib - 36.8 mm

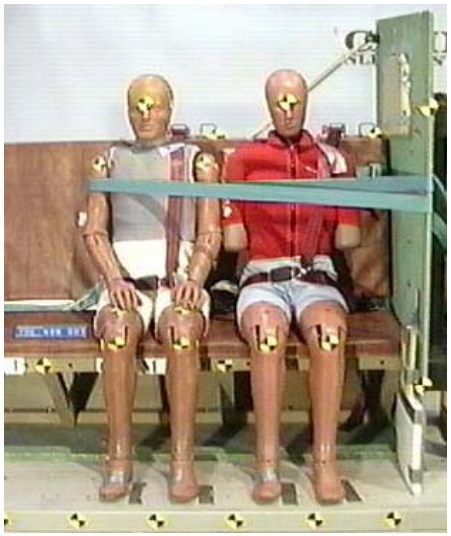
## Unpadded Wall

- Max. pelv. acc. - 150 G
- TTI - 81.8 G
- V*C - 0.93 m/s
- Rib deflections
  - Upper Rib - 50.2 mm
  - Middle Rib - 39.7 mm
  - Lower Rib - 36.5 mm

**Padding resulted in lower rib and pelvic accelerations**

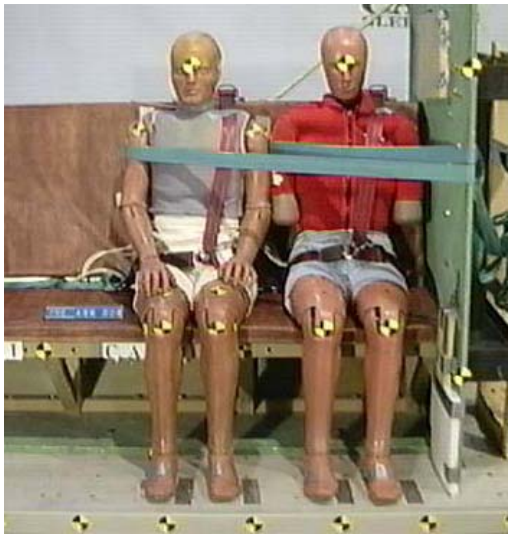
**No significant effect on rib deflections**

# EuroSID-1 Tests with Multi-Occupant Seating



**EuroSID & Hybrid II**

**72-in couch**



**Distance to Barrier - 15.75 in.**

- Distance between ATDs - 19.5 in.
- Max. pelvic acc. - 150.0 G
- TTI - 86.6 G
- V*C - 0.99 m/s
- Rib deflection
  - Upper Rib - 55.9 mm
  - Middle Rib - 44.5 mm
  - Lower Rib - 40.0 mm

**Distance to Barrier - 12 in.**

- Distance Between ATDs - 19 in.
- Max. pelvic acc. - 77 G
- TTI - 44.5 G
- V*C - 0.68 m/s
- Rib deflection
  - Upper Rib - 59.0 mm
  - Middle Rib - 46.2 mm
  - Lower Rib - 40.9 mm

**Occupant closer to barrier exhibited lower rib and pelvic accelerations**

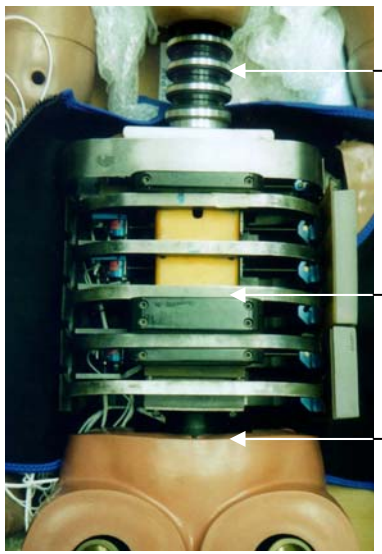
**Rib deflections are too high**

# Summary of EuroSID-1 Test Results

| CAMI Test # | ATD Type & order | Distance to Barrier (in.) | Distance b/w ATD (in.) | Lap Belt Spacing (in.) | Max. Pelvic Accel (G's) | TTI (G's) | Rib Deflections (mm) | | | $V*C_{max}$ (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Upper Rib | Middle Rib | Lower Rib | |
| A98005 | EuroSID | 15.75 | N/A | 21 | 105 | 64.9 | 45.0 | 39.9 | 36.8 | 0.74 |
| A98006 | EuroSID | 15.75 | N/A | 21 | 150 | 81.8 | 50.2 | 39.7 | 36.5 | 0.93 |
| A98007 | EuroSID & HII | 15.75 | 19.5 | 21, 20 | 150 | 86.6 | 55.9 | 44.5 | 40.0 | 0.99 |
| A98008 | EuroSID & HII | 12.00 | 19.0 | 21, 21 | 77 | 44.5 | 59.0 | 46.2 | 40.9 | 0.68 |
| A98009 | EuroSID | 19.00 | N/A | 10 | 33.8 | 44.7 | 0 | 0 | 0 | - |
| A98010 | EuroSID | 16.00 | N/A | 10 | 45.2 | 46.7 | 1.5 | 0 | - | - |

# SFS Tests with BioSID

- In addition to TTI, pelvic accl, rib deflections and V*C, BioSID provides:
  - Illiac force
  - Upper neck moment in X-direction and force in Y-direction
  - Larger rib deflection measurements capability (up to 75 mm) compared to EuroSID-1



# BioSID Tests with Single Occupant Seating

**Distance to barrier - 15.75 in.**

**72-in couch**

**Unpadded Wall**

- Max. pelvic acc. - 119G
- TTI - 79 G
- V*C - 1.1 m/s
- Rib deflection
  - Upper Rib - 48 mm
  - Middle Rib - **
  - Lower Rib - 50 mm

**Padded Wall**

- Max. pelvic acc. - 83 G
- TTI - 67 G
- V*C - 1.14 m/s
- Rib deflection
  - Upper Rib - 53 mm
  - Middle Rib - **
  - Lower Rib - 55 mm

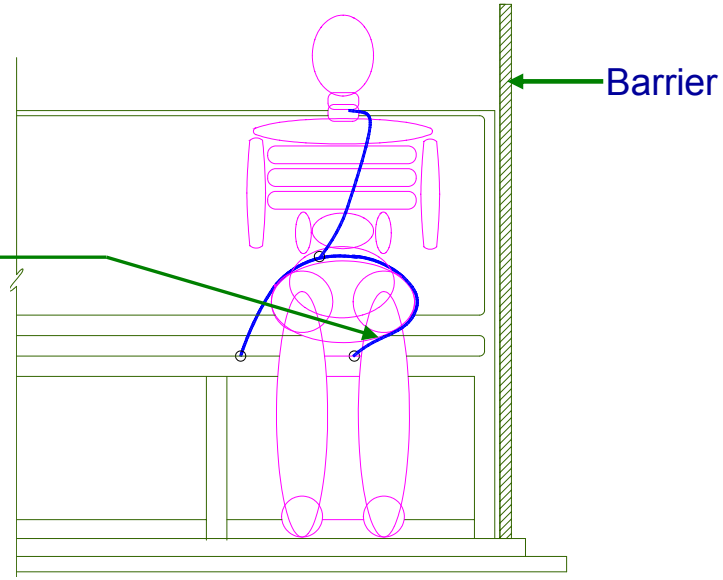
**Padding resulted in lower rib and pelvic accelerations**

# Summary of BioSID Test Results

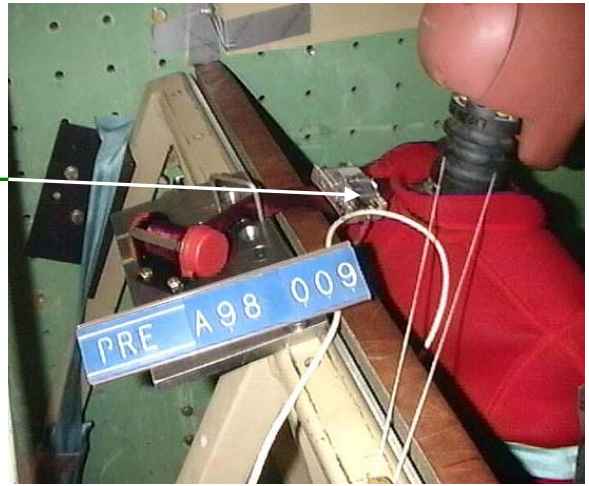
| CAMI Test # | ATD Type & order | Dist. To barrier (in.) | Lap Belt Spacing (in.) | Max. Pelvic Accel (G's) | TTI (G's) | Rib Deflections (mm) | | | Viscous Criteria (m/s) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Upper Rib | Middle Rib | Lower Rib | |
| A98011 | BioSID | 16.00 | 10 | 34.5 | 74.2 | 11.9 | - | 7.5 | 0.12 |
| A98012 | BioSID | 16.00 | 10 | 35.0 | 74.5 | 9.7 | - | 8.9 | 0.1 |
| A98014 | BioSID | 15.75 | 21 | 119.0 | 78.8 | 48.0 | - | 50.5 | 1.1 |
| A98015 | BioSID | 15.75 | 21 | 83.4 | 67.3 | 52.7 | - | 54.5 | 1.14 |

# Potential Restraint System Configurations

- Body-centered belt (BC)
  - Forward lap belt was anchored behind the pelvis

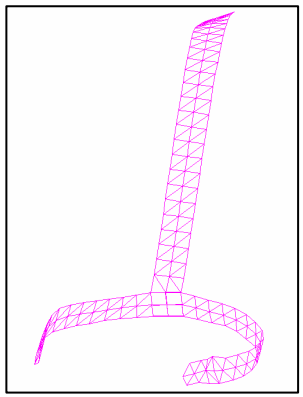



  - Shoulder anchorage centered behind the neck (BN)

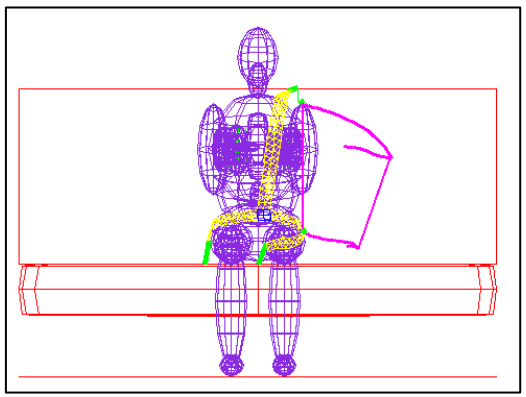


# Body-Centered Belt Wrapping

- Lower torso lateral excursion of 6-in.
  - Photometric analysis of EuroSID-1 ATD motion in the Tests
  - Also demonstrated by analytical modeling



**FEM Belt**



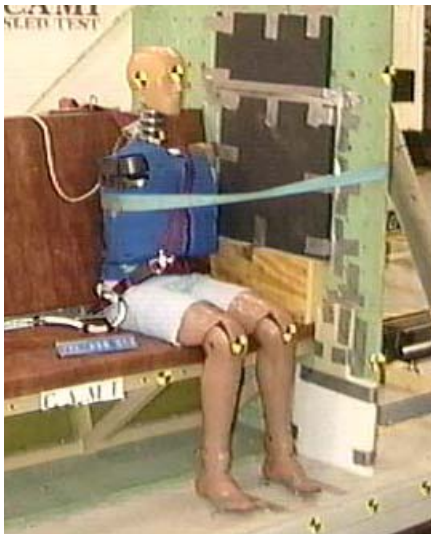
**Body Envelope**

**EuroSID ATD**

# EuroSID and BioSID Test Results with Body-Centered Belt Wrapping

**Test A98010 - EuroSID**

- Distance to Barrier - 16.00 in.
- Max. pelvic acc. - 45.2 G
- TTI - 49.0 G
- Rib deflection
  - Upper Rib - 0 mm
  - Middle Rib - 0 mm
  - Lower Rib - 0 mm
- **No Contact**



**Test A98012 - BioSID**

- Distance to Barrier - 16.00 in.
- Max. pelvic acc. - 35 G
- TTI - 74.5 G
- Rib deflection
  - Upper Rib - 9.7 mm
  - Middle Rib - 0 mm
  - Lower Rib - 8.9 mm

- **Minimized lateral excursion of body**
- **Can eliminate body-to-body/ body-to-wall contact**
- **Demonstrated potential to minimize the accelerations, compression and forced based criteria**

# Comparison of SID, EuroSID & BioSID Tests

## Test Results with Single Occupant Seating

### Test A96107 - SID

- 72-in couch
- Distance to barrier - 15.75 in.
- TTI - 95 G
- Max. pelv. acc. - 101 G

### Test A98006 - EuroSID

- 72-in couch
- Distance to barrier - 15.75 in.
- Max. pelv. acc. - 150 G
- TTI (G's) - 82
- V*C - 0.93 m/s
- Rib deflections
  - Upper Rib - 50.2 mm
  - Middle Rib - 39.7 mm
  - Lower Rib - 36.5 mm

### Test A98014 - BioSID

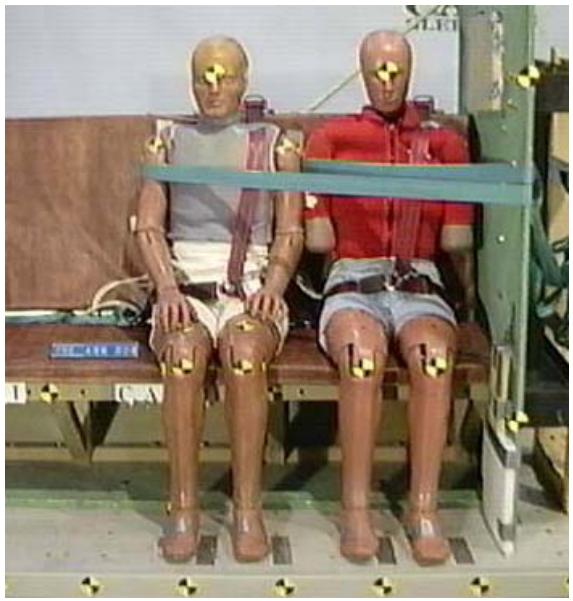
- 72-in couch
- Distance to barrier - 15.75 in.
- Max. pelv. acc. - 119 G
- TTI (G's) - 79
- V*C - 1.1 m/s
- Rib deflections
  - Upper Rib - 48.0 mm
  - Middle Rib - - mm
  - Lower Rib - 50.5 mm

**TTI results were consistent, with SID somewhat higher**

# Test Results with Multiple-Occupant Seating

## Test A97063 - SID & HII

- Occupant Order - SID & HII
- Distance to Barrier - 12 in.
- Distance Between ATDs - 18 in.
- Lap-belt Spacing - 21, 21 in.
- Max. pelvic acc. - 87 G
- TTI - 69 G

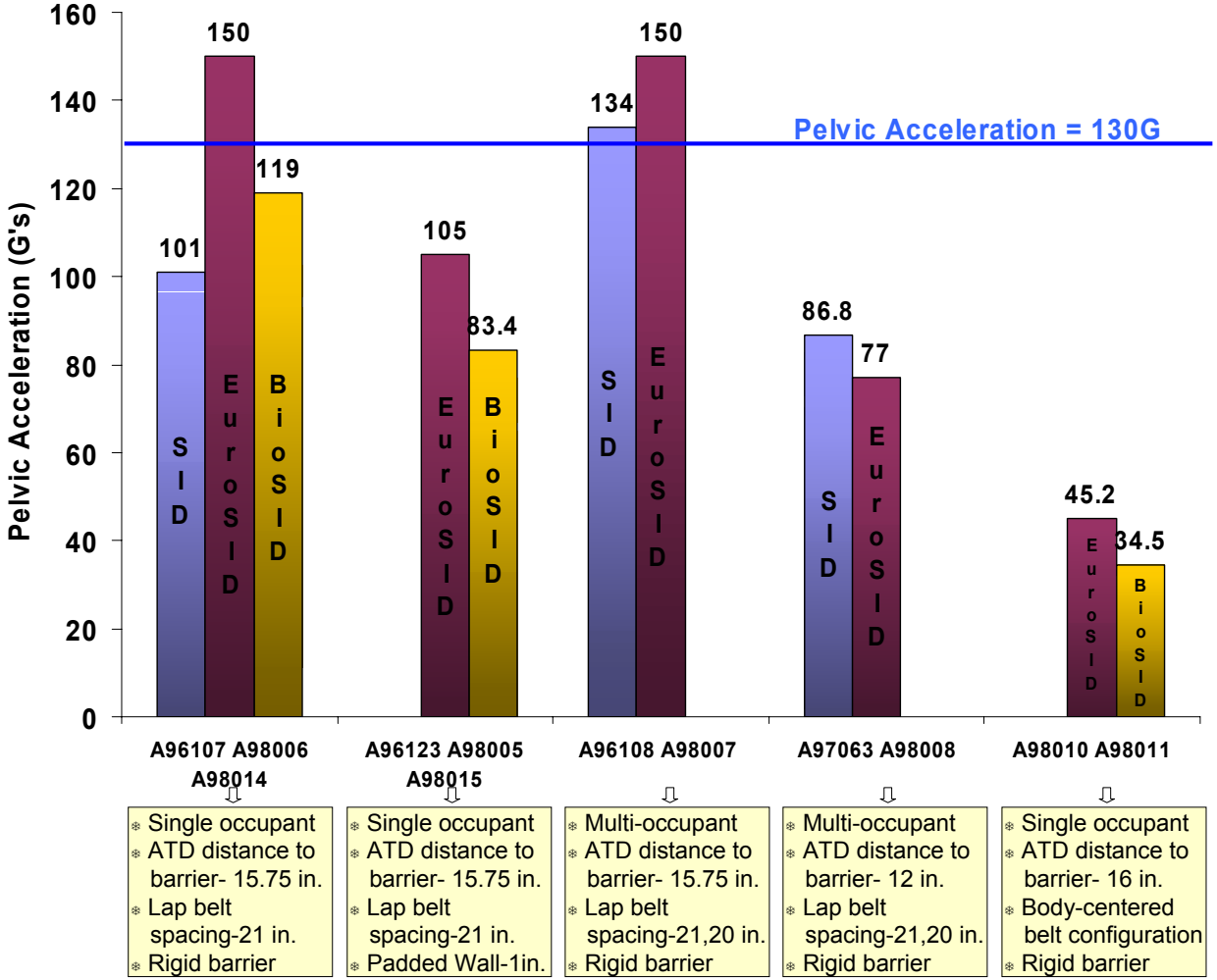


## Test A98008 - EuroSID & HII

- Occupant Order - EuroSID & HII
- Distance to Barrier - 12 in.
- Distance Between ATDs - 19 in.
- Lap-belt Spacing - 21, 21 in.
- Max. pelvic acc. - 77 G
- TTI - 45 G
- V*C - 0.68 m/s
- Rib deflection
  - Upper Rib - 59.0 mm
  - Middle Rib - 46.2 mm
  - Lower Rib - 40.9 mm

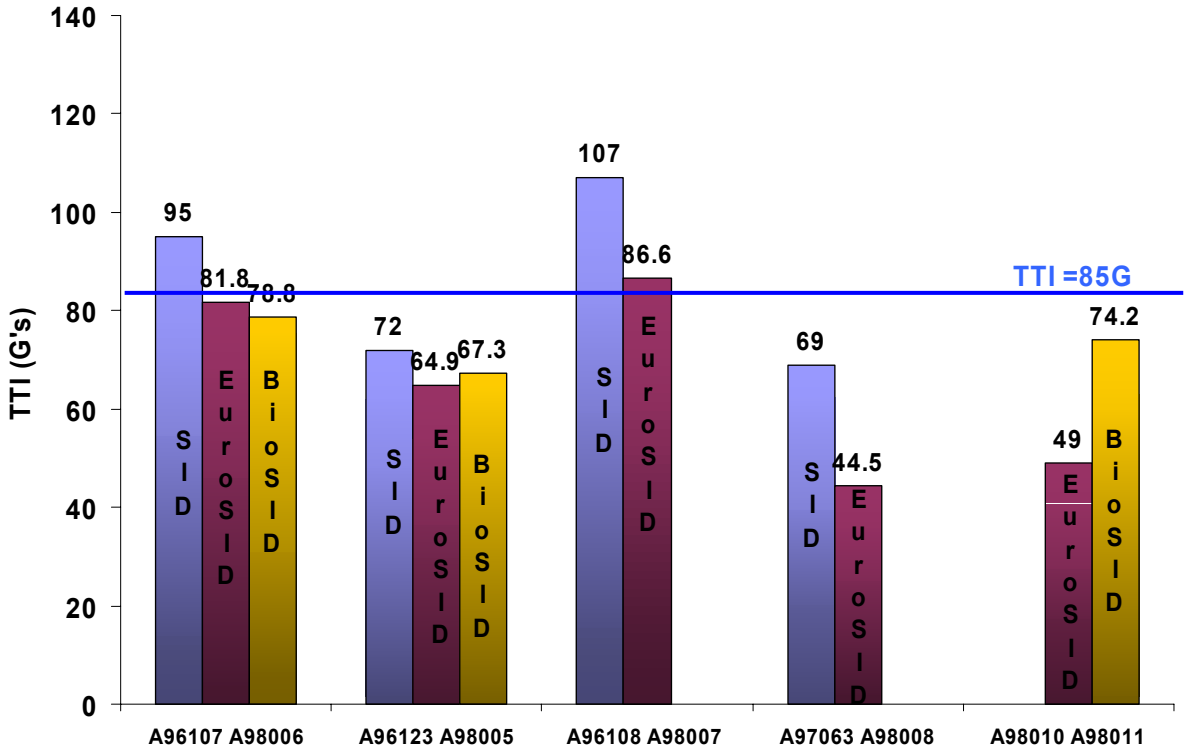
**TTI results with SID ATD were higher**

# Significant Results - Pelvic Acceleration




**Pelvic acceleration were below the threshold for an ATD centerline distance of 15-in. or less from rigid barrier**

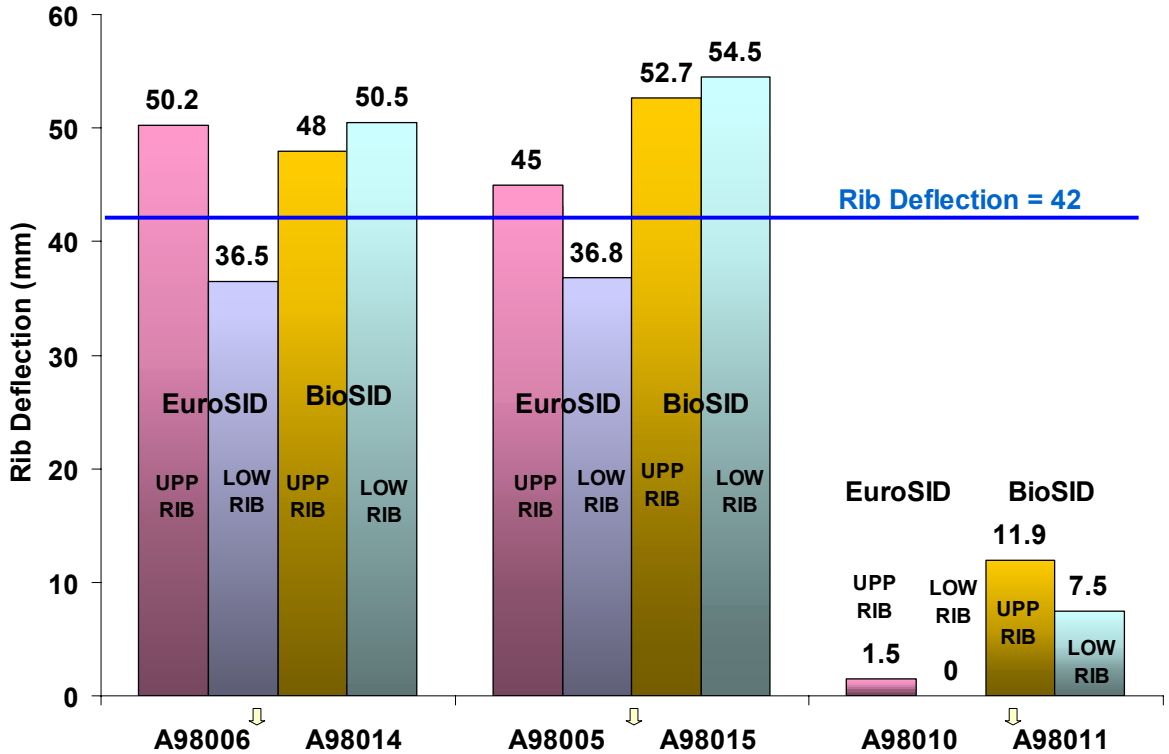
# Significant Results (Cont'd) - TTI




| A96107 A98006 A98014 | A96123 A98005 A98015 | A96108 A98007 | A97063 A98008 | A98010 A98011 |
|---|---|---|---|---|
| Single occupant<br>ATD distance to barrier- 15.75 in.<br>Lap belt spacing-21 in.<br>Rigid barrier | Single occupant<br>ATD distance to barrier- 15.75 in.<br>Lap belt spacing-21 in.<br>Padded Wall-1 in. | Multi-occupant<br>ATD distance to barrier- 15.75 in.<br>Lap belt spacing-21,20 in.<br>Rigid barrier | Multi-occupant<br>ATD distance to barrier- 12 in.<br>Lap belt spacing-21,20 in.<br>Rigid barrier | Single occupant<br>ATD distance to barrier- 16 in.<br>Body-centered belt configuration<br>Rigid barrier |

**TTI values are below the threshold for a ATD centerline distance of 12-in. or less from rigid barrier**

# Significant Results (Cont'd) - Rib Deflections




- Single occupant
- ATD distance to barrier- 15.75 in.
- Lap belt spacing-21 in.
- Rigid barrier

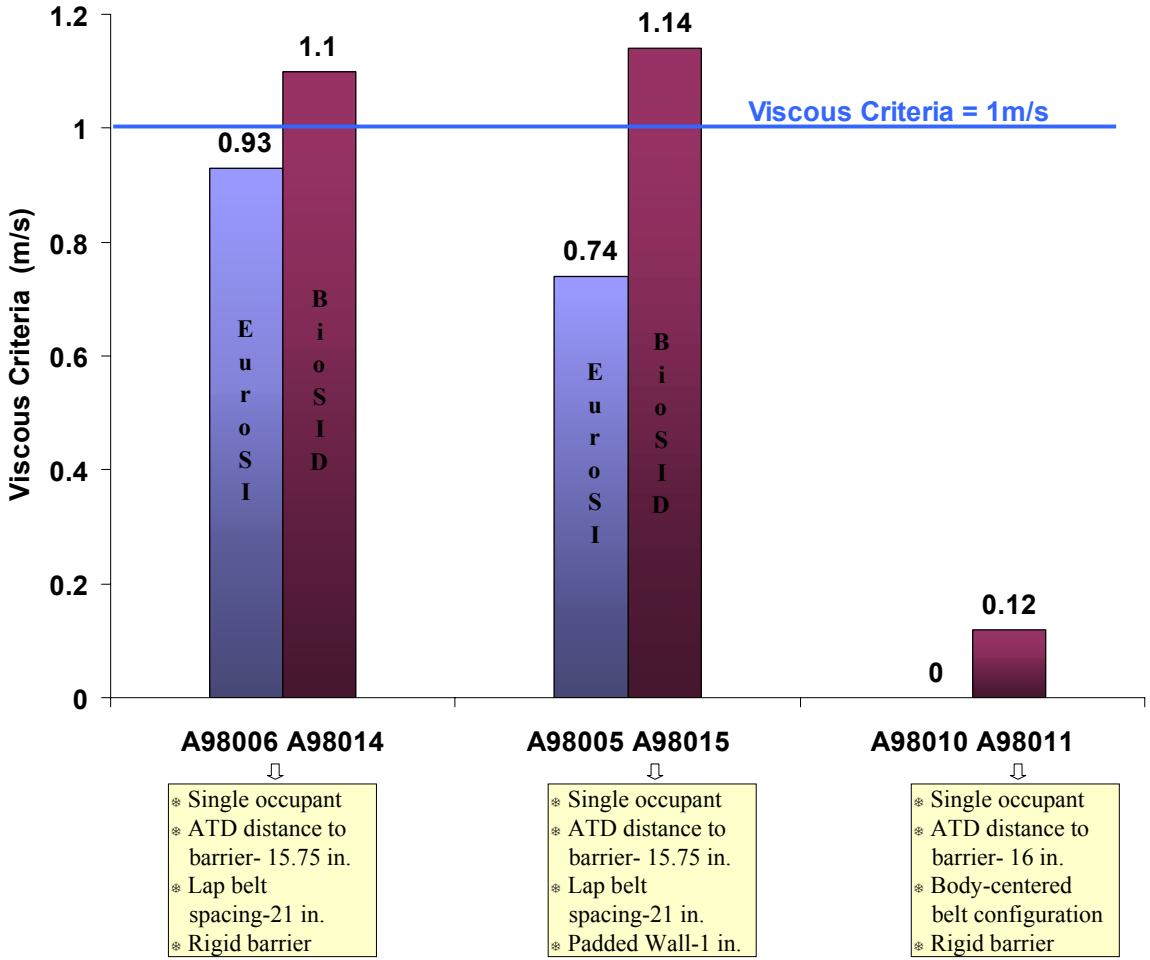
- Single occupant
- ATD distance to barrier- 15.75 in.
- Lap belt spacing-21 in.
- Padded Wall-1 in.

- Single occupant
- ATD distance to barrier- 16 in.
- Body-centered belt configuration
- Rigid barrier

**Rib deflections were in general higher than automotive industry accident data**

**Body-centered belt wrapping minimized rib deflection**

# Significant Results (Cont'd) - Viscous Criteria




**V*C values were near the pass/fail threshold in most cases.**

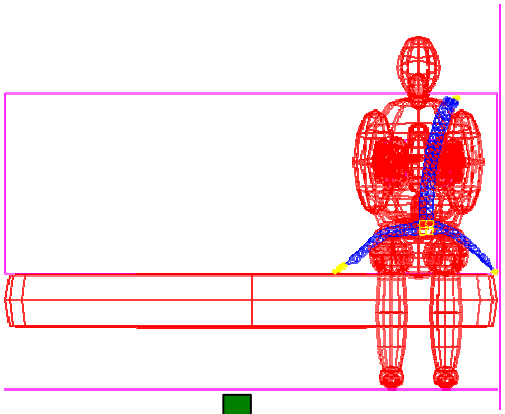
**Body-centered belt wrapping minimized V*C**

# Modeling the SFS Tests

- Develop a platform for conducting parametric studies

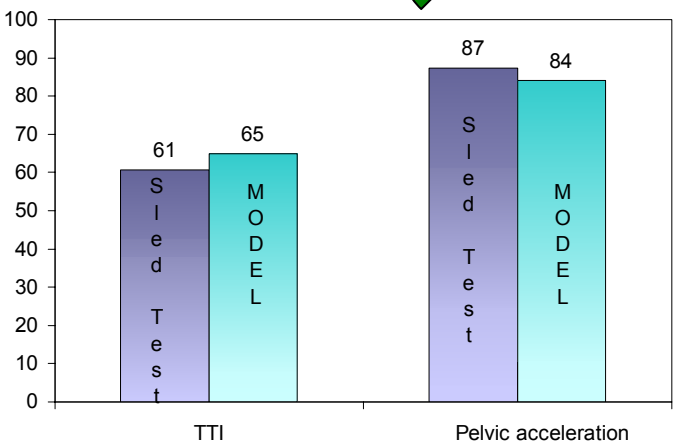
**MADYMO Validation**

**Distance to barrier - 12 in**



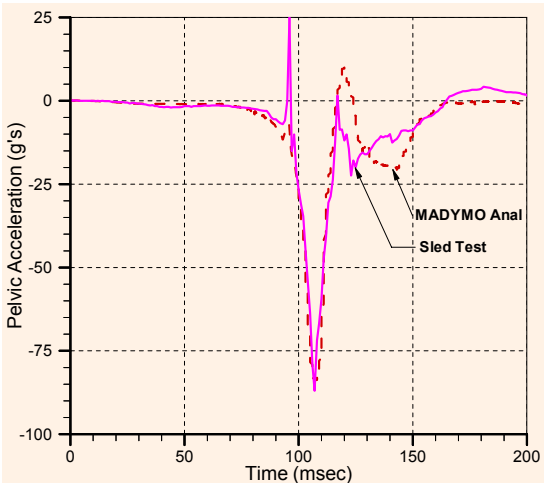
**Profile Comparison**

**TTI & Pelvic Acceleration in Good Agreement**



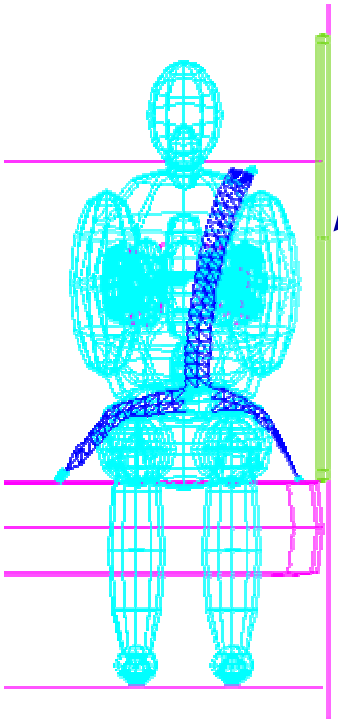

**Peak Injury Values**

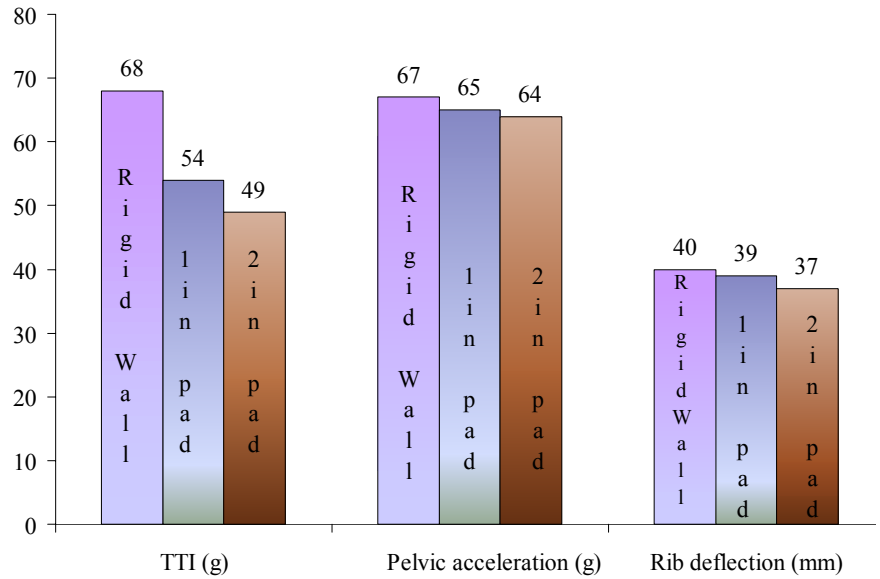
**Comparison**



# Parametric Study: Effect of Padding

- IV3 Foam on rigid barrier
  1-in and 2-in thick

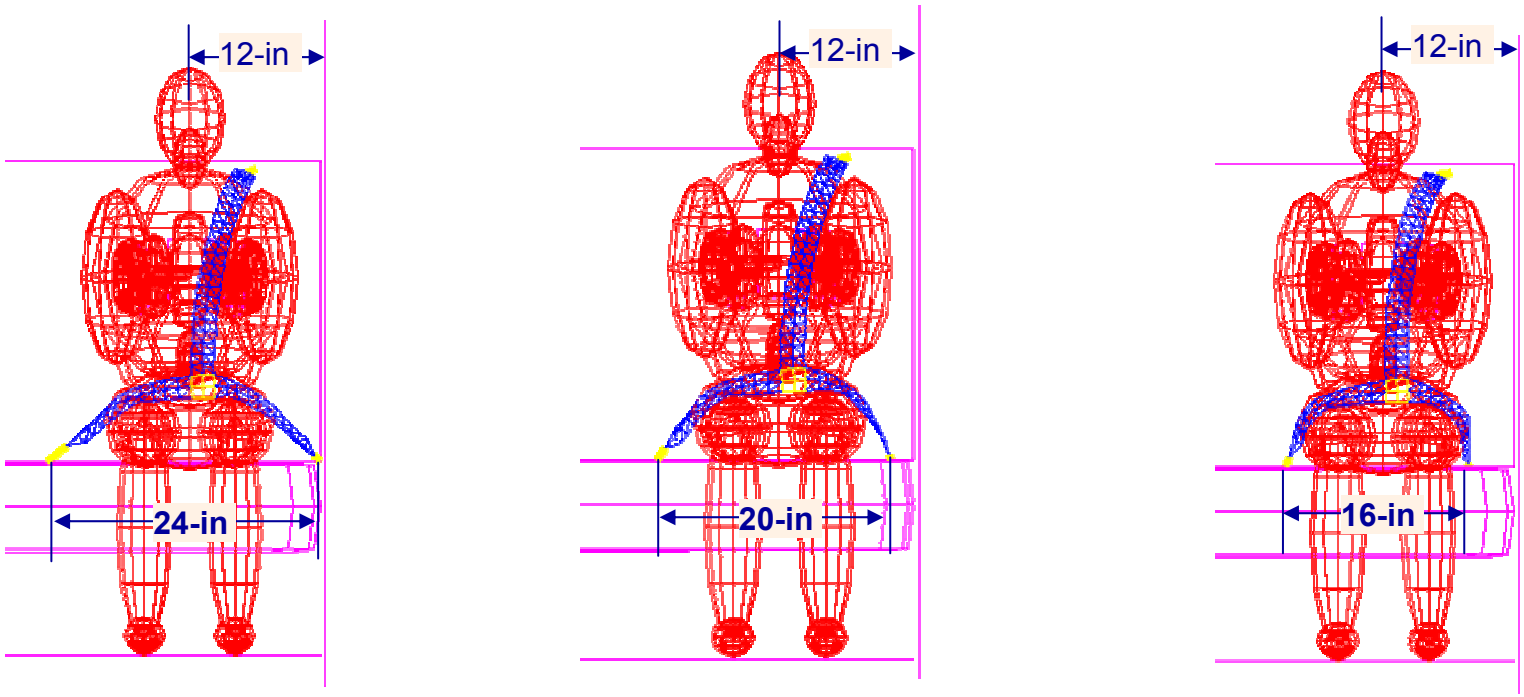



- ***Padding lowered acceleration values***
- ***No significant change in deflections***

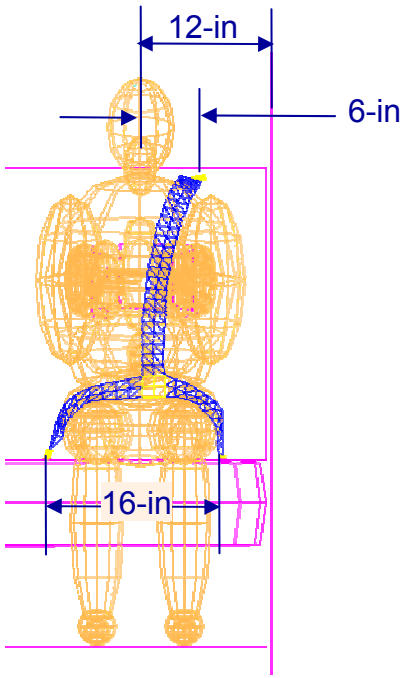
# Parametric Study: Effect of Lap Belt Spacing

- Spacing of: 24, 20, 16-in

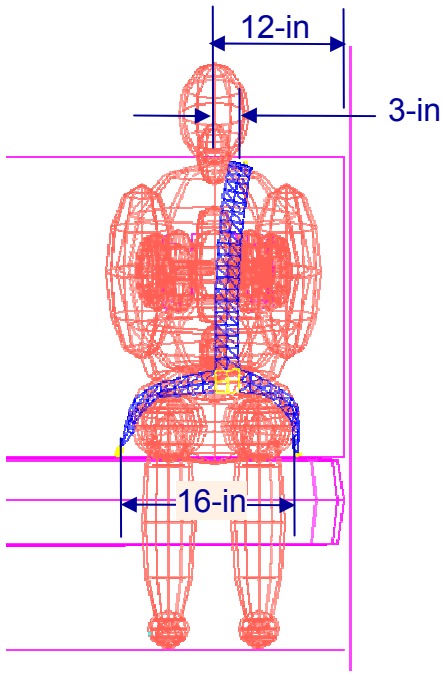



- ***No Significant change in body displacement, TTI, and rib deflection***
- ***16-in, yielded the lowest pelvic acceleration***

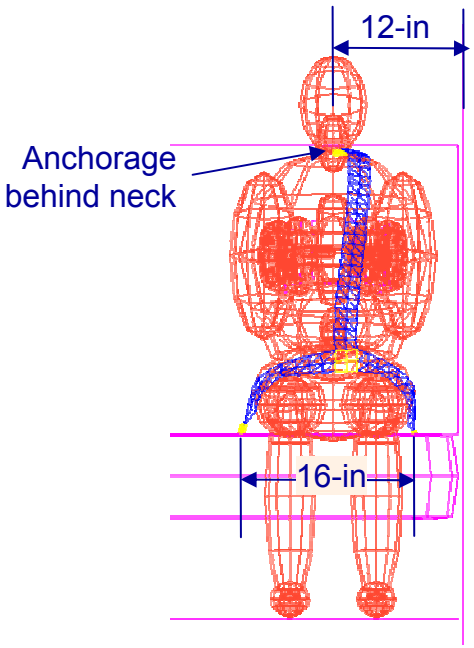
# Parametric Study: Effect of Shoulder Belt Anchorage Point




**Anchorage at 6-in.**




**Anchorage at 3-in.**

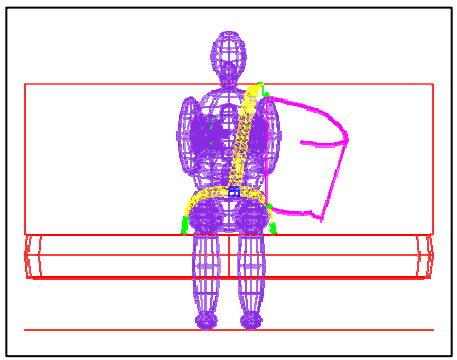



**Anchorage Behind Neck**

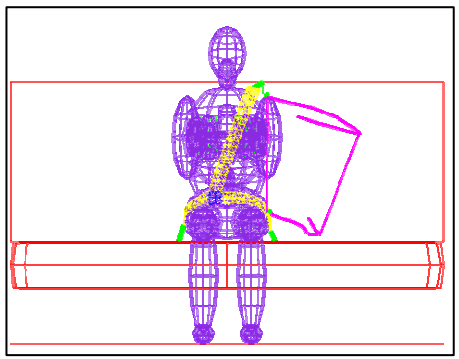
- ***TTI and Rib deflections are lowered***

# Parametric Study: Effect of Buckle Position

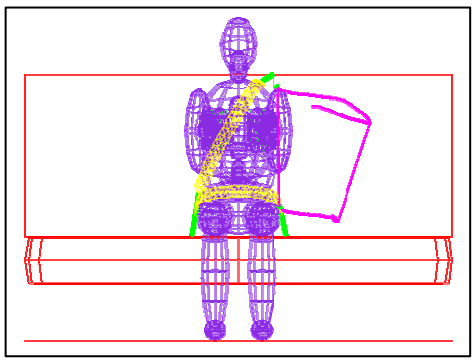
- Buckle positions: center, towards right, extreme right
- ATD in the middle of the couch
- Body-centered belt configuration



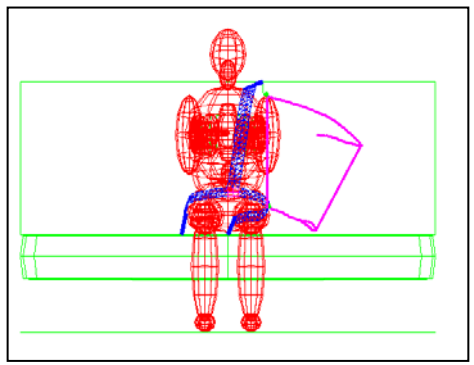
**Center**



**Towards Right**



**Extreme Right**

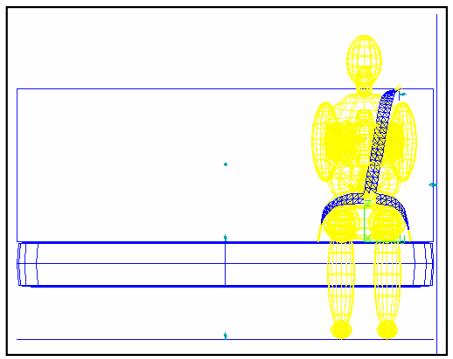


**Body-centered belt**

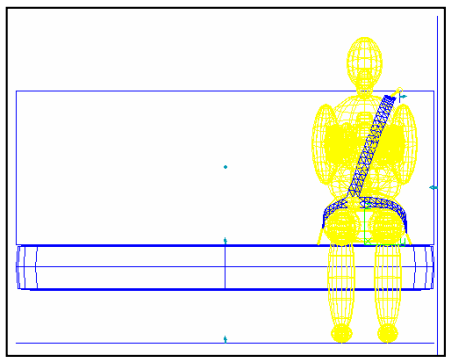
- ***No significant effect on lateral excursion on buckle locations***
- ***Body-centered belt provided least excursion***

# Effect of Buckle Position (cont.)

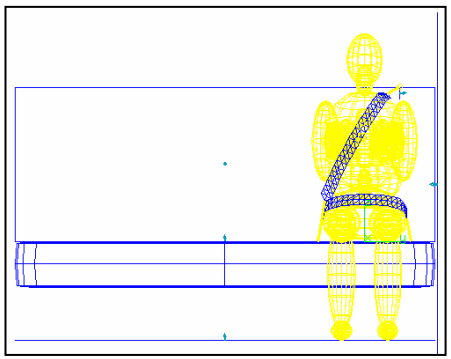
- Buckle Positions: center, towards right, extreme right
- ATD next to rigid barrier
- Body-centered belt wrapping



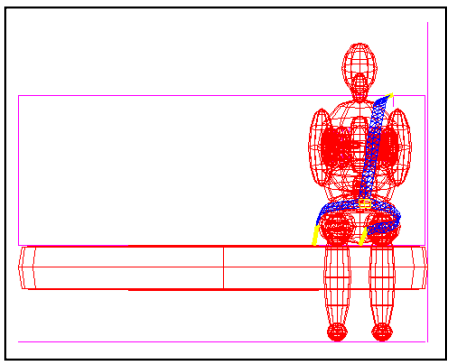
center



Towards Right



Extreme Right



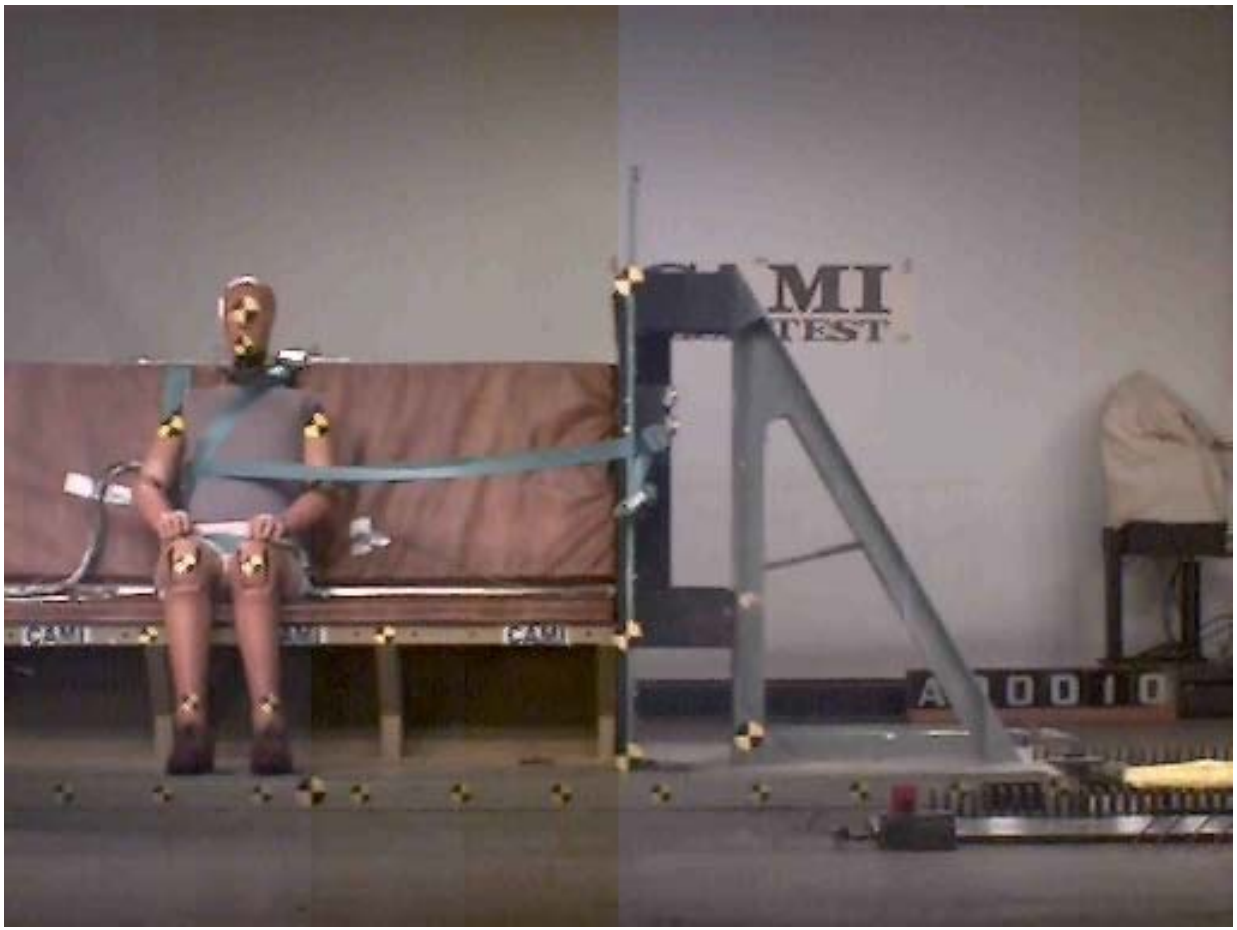
Body-centered belt

- ***TTI is smallest for buckle position in the middle***
- ***Body-centered belt resulted in smallest TTI and pelvic acceleration***

# Summary of Parametric Studies

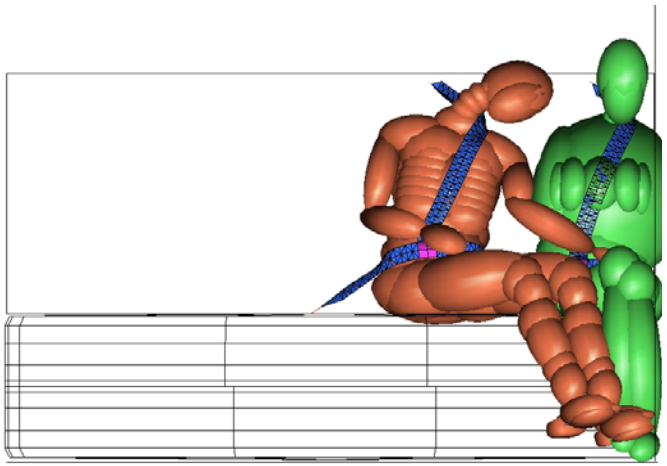
- The TTI values for the extreme buckle positions are highest, while it is low for middle and body-centered positions.
- Pelvic acceleration for the body-centered configuration is least when compared to all the other configurations.
- Shoulder harness and lap belt forces are lesser when placed next to a barrier, as the lateral movement is less.
- TTI values are lesser when the ATD has a lap belt spacing of 16 in.
- Pelvic acceleration is least for a 16 in. lap belt spacing.
- Padding reduces the TTI values but not the rib deflections. Increasing the padding thickness does not lead to significant lowering of compression and acceleration values.

# Observation from Dynamic Tests: Excessive Lateral Neck Rotation



# Proposed Aircraft Side Impact Neck Injury Criteria

- Limited data is available on neck injuries in side impact
- The current Nij criteria may not be suitable for side facing aircraft seats as the impact condition is significantly less than the velocity change experienced in aircrafts accidents
- Australian Army's TRANSAFE research offered some insight as tests have been done with side facing bench seats used as rear seats in military trucks
- Number of automotive cadaver-sled and cadaver car lateral impact test results were reviewed but none gave any clear tolerance limits

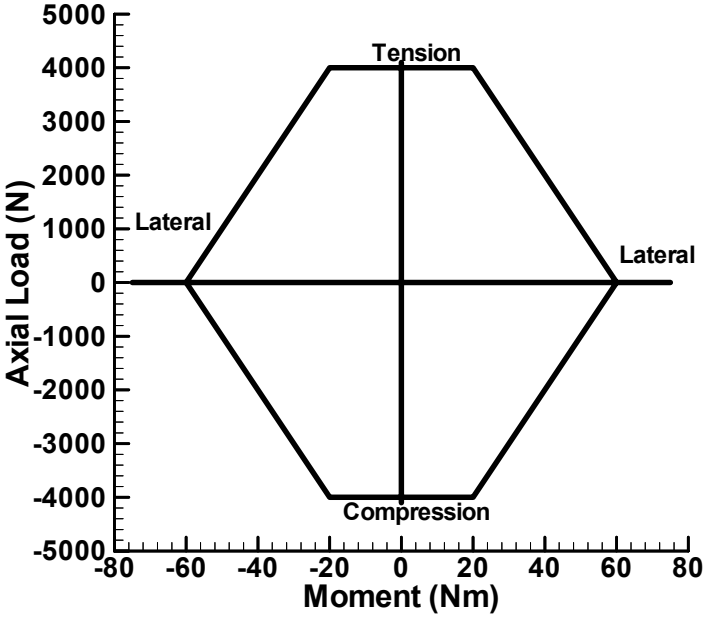


**Occupant experiencing Lateral neck load in side facing seat**

# Proposed Aircraft Side Impact Neck Injury Criteria (Cont'd)

- Candidate tolerance limits for neck loading have been proposed by the Federal Aviation Administration (NRS:Mr. Steve Soltis)
  - Based On Kinematics
    - Lateral neck flexion < 60 degrees
    - Peak head linear acceleration < 36G
    - Peak angular head acceleration < 2600 rad/s$^2$
    - HIC < 1000 (in case of head impact)
  - Based on peak axial loads and moments measured in neck

| Dummy Size | Peak Values | | |
|---|---|---|---|
| 50% Male | Tension (N) | | Compression (N) |
| | 4170 | | 4000 |
| | Nij Intercepts | | |
| 50% Male | Tension (N) | Compressio (N) | Lateral moment (Nm) |
| | 6806 | 6160 | 60 |



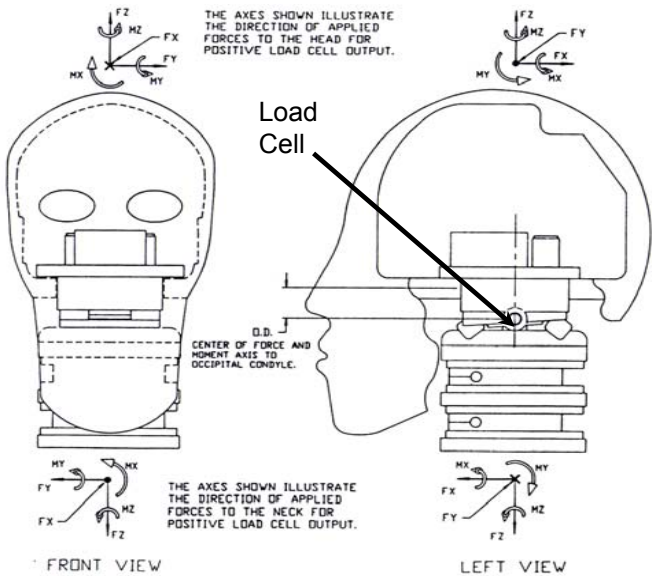

  - NHTSA's intercepts have been used in defining the Nij injury criteria

# Proposed Aircraft Side Impact Neck Injury Criteria (Contd.)

- CAMI/FAA has proposed the following maximum limits
  - Lateral bending moment Mx < 487 inch-lbs
  - Tensile force Fz < 1530 lbs
  - Compressive force Fz < 1200 lbs
  - Lateral shear force Fy < 250 lbs
- During the impact response period, the combination of Fz and Mx must be within the following limits

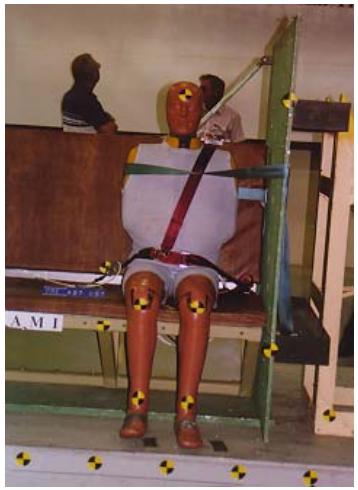
$$Nij = \left(\frac{Mx}{487}\right) + \left(\frac{Fz}{1530}\right) < 1.0$$

- Some of the tests conducted at CAMI were reproduced using MADYMO
- Neck injuries were evaluated for these tests
- A parametric study was conducted using the model

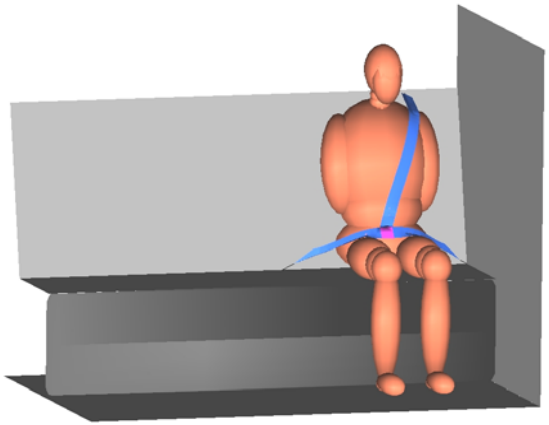



**Hybrid III Upper Neck Load Cell Orientation**

# Sample of Modeling and Validation



Sled initial position

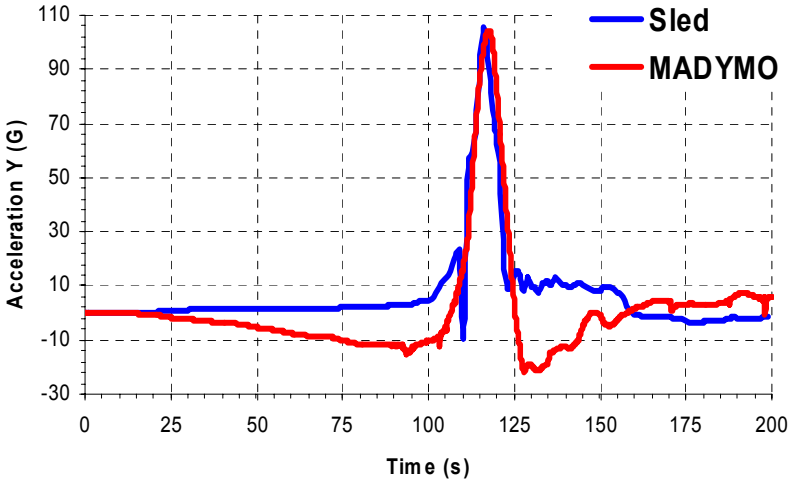


MADYMO model using FSID

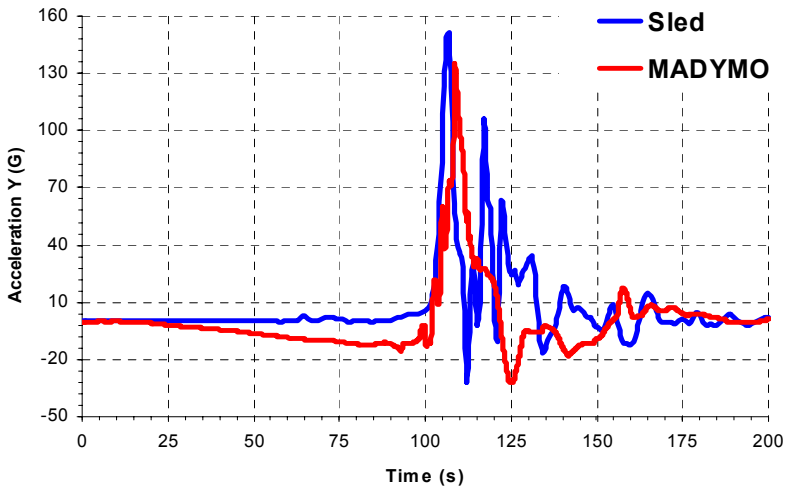
## Comparison of Sled Test A97057 and MADYMO results

| Injury Parameter (peak values) | Sled test | MADYMO |
|---|---|---|
| ***Accelerations (g's)*** | | |
| Upper chest acceleration | 150.5 | 129.0 |
| Lower chest acceleration | 143.5 | 131.4 |
| Lower spine acceleration | 76.3 | 70.1 |
| **TTI** | **99.7** | **102.6** |
| Pelvic acceleration | 108.5 | 104.5 |

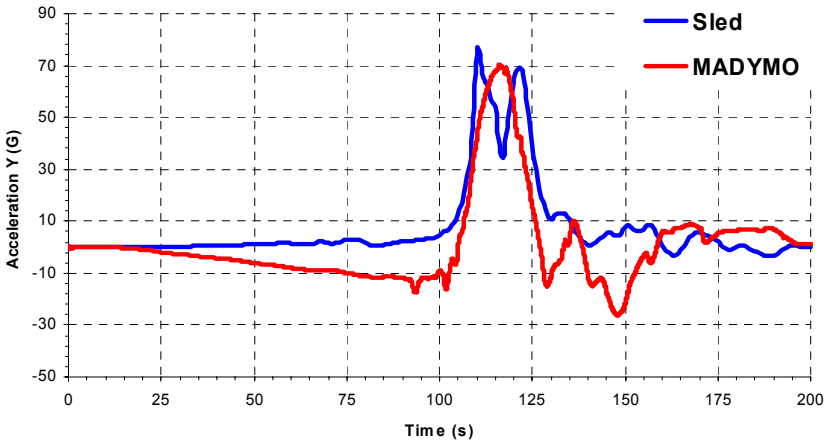
# Comparison of Sled Test and MADYMO Model Acceleration Profiles



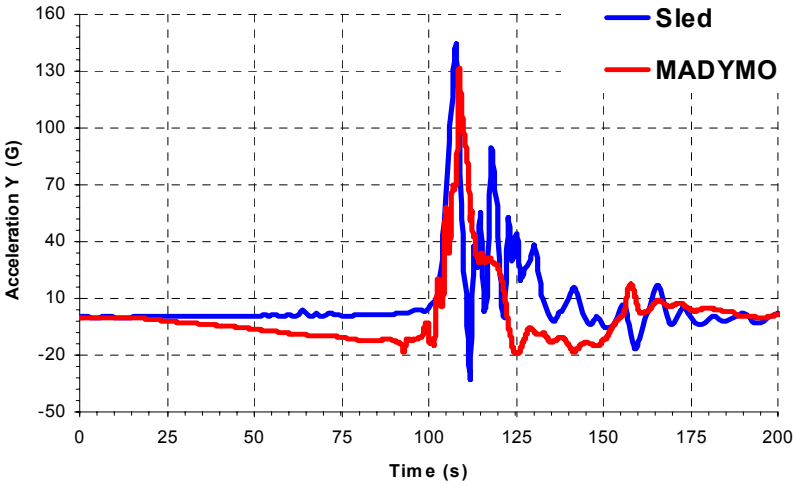

Pelvic acceleration




Upper Chest acceleration




Lower Spine acceleration




Lower Chest acceleration

# Parametric Study

## Matrix used for Parametric Study

| | Test Set | ATD Type & Order | Distance to barrier | Distance Between ATD's | Lap Belt Spacing | Buckle Type | Shoulder Belt Position |
|---|---|---|---|---|---|---|---|
| Series 1 | 1.1 | FSID | 12 | - | 16 | 1 | - |
| | 1.2 | FSID | 12 | - | 16 | 2 | - |
| | 1.3 | FSID | 12 | - | 16 | 3 | - |
| | 1.4 | FSID | 36 | - | 16 | 1 | - |
| | 1.5 | FSID | 36 | - | 16 | 2 | - |
| | 1.6 | FSID | 36 | - | 16 | 3 | - |
| | 1.7 | FSID | 12 | - | 20 | 1 | - |
| | 1.8 | FSID | 12 | - | 20 | 2 | - |
| | 1.9 | FSID | 12 | - | 20 | 3 | - |
| | 1.10 | FSID | 36 | - | 20 | 1 | - |
| | 1.11 | FSID | 36 | - | 20 | 2 | - |
| | 1.12 | FSID | 36 | - | 20 | 3 | - |
| Series 2 | 2.1 | FSID | 12 | - | BC | - | - |
| | 2.2 | FSID | 36 | - | BC | - | - |
| | 2.3 | FSID | 12 | - | BC | - | BN |
| | 2.4 | FSID | 36 | - | BC | - | BN |
| Series 3 | 3.1 | FSID & HIII | 12 | 24 | 20,20 | 1 | - |
| | 3.2 | FSID & HIII | 12 | 24 | 16,16 | 1 | - |
| | 3.3* | FSID & HIII | 12 | 24 | 16,16 | 1 | - |
| | 3.4 | FSID & HIII | 12 | 18 | 16,16 | 1 | - |

* Rigid armrest is considered; BC Body Centered Lap belt positioning; BN Behind Neck, Shoulder belt positioning

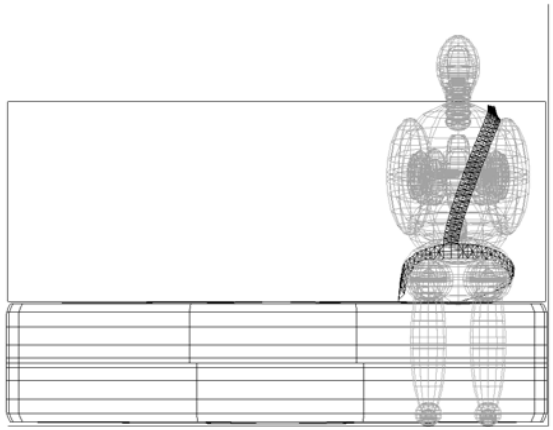
# Results from Series-1 Parametric Study

| Test Set | Distance to Barrier | Lap Belt Spacing | Buckle Type* | Pelvic Acc. < 130 G | TTI < 85 G | Mx < 487 inch-lbs | Fz < 1530 lbs | Fy < 250 lbs | Nij < 1.0 |
|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 12 | 16 | 1 | 43.6 | 52.6 | 811.2 | 853.3 | 230.2 | 2.22 |
| 1.2 | 12 | 16 | 2 | 55.4 | 52.2 | 823.2 | 838.8 | 241.0 | 2.24 |
| 1.3 | 12 | 16 | 3 | 90.9 | 57.6 | 505.2 | 592.3 | 387.1 | 1.42 |
| 1.4 | 36 | 16 | 1 | 42.7 | 32.6 | 626.8 | 438.2 | 248.0 | 1.57 |
| 1.5 | 36 | 16 | 2 | 41.9 | 33.1 | 1023.5 | 478.7 | 393.6 | 2.41 |
| 1.6 | 36 | 16 | 3 | 95.6 | 36.7 | 1045.2 | 409.7 | 574.7 | 2.41 |
| 1.7 | 12 | 20 | 1 | 38.7 | 55.5 | 614.1 | 205.1 | 361.6 | 1.39 |
| 1.8 | 12 | 20 | 2 | 51.6 | 49.6 | 940.8 | 664.9 | 209.2 | 2.37 |
| 1.9 | 12 | 20 | 3 | 90.5 | 54.4 | 837.2 | 815.2 | 241.7 | 2.25 |
| 1.10 | 36 | 20 | 1 | 48.4 | 41.1 | 687.6 | 340.7 | 287.0 | 1.63 |
| 1.11 | 36 | 20 | 2 | 94.7 | 44.8 | 835.9 | 473.5 | 333.7 | 2.02 |
| 1.12 | 36 | 20 | 3 | 162.1 | 53.9 | 1219.1 | 372.6 | 492.5 | 2.75 |

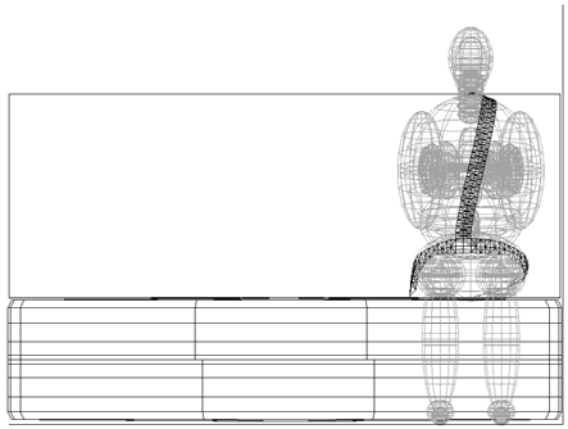
1 Mid Buckle Position
2 Right Buckle Position
3 Extreme Buckle Position

# Results from Series-2 Parametric Study

## Initial Position



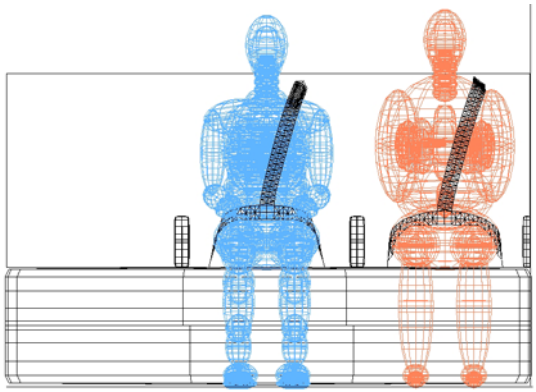
**BC belt configuration**



**BN - BC belt configuration**

| Test Set | Distance to barrier | Belt Config. | Pelvic Acc. < 130 G | TTI < 85 G | Mx < 487 inch-lbs | Fz < 1530 lbs | Fy < 250 lbs | Nij < 1.0 |
|---|---|---|---|---|---|---|---|---|
| 2.1 | 12 | BC | 14.7 | 61.6 | 972.6 | 998.8 | 232.7 | 2.65 |
| 2.2 | 36 | BC | 18.5 | 27.5 | 727.2 | 441.9 | 328.9 | 1.78 |
| 2.3 | 12 | BC-BN | 14.4 | 54.6 | 635.9 | 536.1 | 313.9 | 1.66 |
| 2.4 | 36 | BC-BN | 29.8 | 32.6 | 516.3 | 375.6 | 224.2 | 1.31 |

# Results from Series-3 Parametric Study



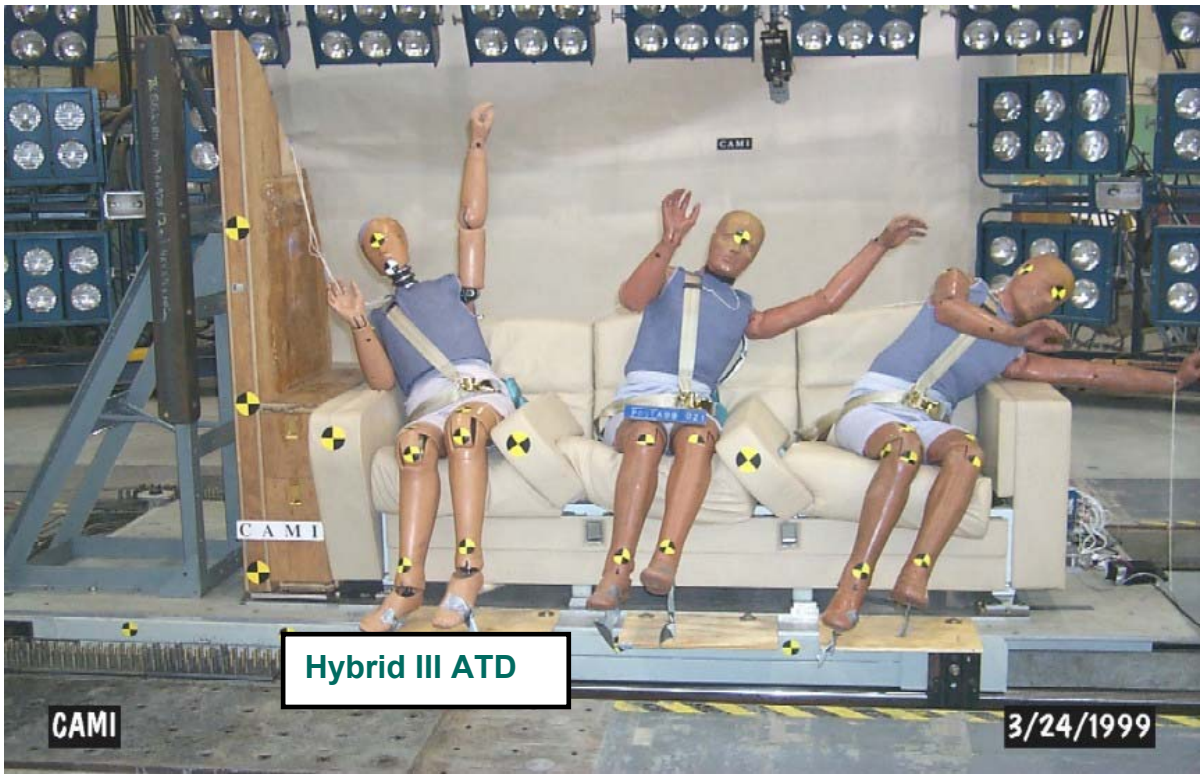
| Test Set | ATD Type & Order | Distance Between ATDs | Lap Belt Spacing | Pelvic Acc. < 130 G | TTI < 85 G | Mx < 487 inch-lbs | Fz < 1530 lbs | Fy < 250 lbs | Nij < 1.0 |
|---|---|---|---|---|---|---|---|---|---|
| 3.1 | FSID & HIII | 24 | 20<br>20 | 38.7 | 55.6 | 595.6<br>743.8 | 205.3<br>373.7 | 361.7<br>332.8 | 1.36<br>1.77 |
| 3.2 | FSID & HIII | 24 | 16<br>16 | 33.3 | 49.5 | 1094.8<br>882.2 | -950.6<br>426.5 | 257.8<br>340.2 | 2.87<br>2.09 |
| 3.3* | FSID & HIII | 24 | 16<br>16 | 34.5 | 48.2 | 1109.3<br>1025.6 | -912.6<br>442.3 | 278.3<br>337.4 | 2.67<br>2.39 |
| 3.4 | FSID & HIII | 18 | 16<br>16 | 33.2 | 48.9 | 941.5<br>673.1 | -795.6<br>393.8 | 266.2<br>305.3 | 2.45<br>1.64 |

* Rigid armrest has been used

# Additional SFS Tests Performed at CAMI

| Test Number | ATD Position | Yaw | Restraint Geometry | Torso Belt Top Anchor (Fwd of ATD CL) | Torso Belt Lap Tie Point (Aft of ATD CL) |
|---|---|---|---|---|---|
| **A94168** | ATD CL 11.75” from padded wall | 10 | normal | 3.75” | 4” |
| **A94172** | ATD in center of rigid sofa | 10 | normal | 3.75” | 4” |
| **A96110** | ATD in center of rigid sofa | 10 | normal | 5.0” | 2” |
| **A96111** | ATD in center of rigid sofa | 10 | body centered lap belts, I-Reel | 5.0” | 2” |
| **A96113** | ATD in center of rigid sofa | 10 | body centered lap and torso belts, I-Reel | 0.0” | 2” |
| **A99021** | ATD aft of armrest / closet wall, Falcon 2000 sofa | 0 | normal, I-Reel (9.5” below shoulder height) | 12” | 0” |
| **A00009** | ATD in center of rigid sofa | 0 | continuous loop | 6.0” | 8” |
| **A00010** | ATD in center of rigid sofa | 0 | continuous loop | 6.0” | 8” |
| **A00011** | ATD in center of rigid sofa | 0 | body centered lap and torso belts, I-Reel | 0.0” | -2” |
| **A02003** | ATD in center of rigid sofa | 10 | body centered lap belts, I-Reel | 5.0” | 4” |

# Sample CAMI SFS Test for Neck Injury Evaluation
# A99021: - Sofa, Armrest/Wall - (Post test)



# Result from the Test Performed at CAMI

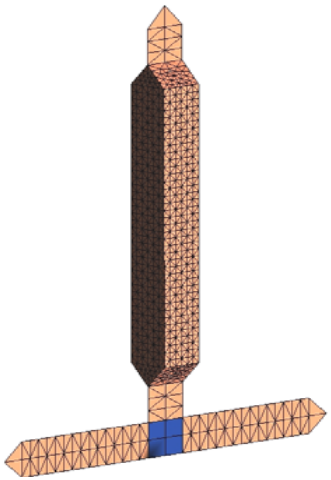
| Test Number | Restraint Geometry | Yaw | Sled X (Gs) | Peak Responses Mx (in.-lbs) | Fz (lbs) | Fy (lbs) | Nij |
|---|---|---|---|---|---|---|---|
| **A94168** | normal [2] | 10 | 15.5 | 874 | 353 | 304 | 1.88 |
| **A94172** | normal [1] | 10 | 17.0 | 865 | 354 | 320 | 2.01 |
| **A96110** | normal [1] | 10 | 16.3 | 944 | 499 | 260 | 2.11 |
| **A96111** | body centered lap belts, I-Reel [1] | 10 | 16.2 | 1146 | 546 | 264 | 2.57 |
| **A96113** | body centered lap and torso belts, I-Reel [1] | 10 | 16.4 | 574 | 362 | 153 | 1.36 |
| **A99021** | normal, I-Reel [3] | 0 | 16.1 | 1399 | -507 | -186 | 2.92 |
| **A00009** | continuous loop [1] | 0 | 11.6 | 587 | 260 | 201 | 1.32 |
| **A00010** | continuous loop [1] | 0 | 16.8 | 809 | 394 | 280 | 1.83 |
| **A00011** | body centered lap and torso belts, I-Reel [1] | 0 | 11.3 | 489 | 368 | 193 | 1.12 |
| **A02003** | body centered lap belts, I-Reel [1] | 10 | 15.1 | 892 | 493 | 295 | 1.99 |

1 ATD in center of rigid sofa
2 ATD CL 11.75” from padded wall
3 ATD aft of armrest / closet wall, Falcon 2000 sofa

# Potential Use of Inflatable Seat Belt

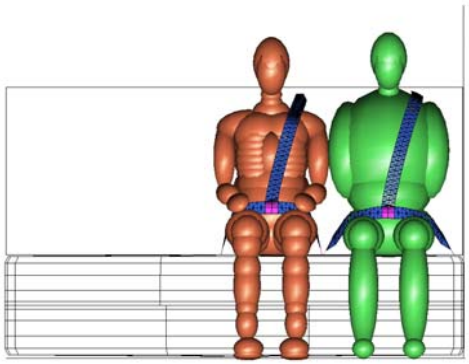
Advantages of Inflatable Seat Belts

- Acts as a seat belt as well as an airbag
- Belt slack is eliminated so that the restraint begins at the earliest possible time during the crash event
- Webbing loads are distributed over a wide area to eliminate belt induced trauma
- It deploys away from the occupant so injuries due to inflation is minimized
- The force between the body and the seat belt is considerably reduced due to cushioning effect provided by the inflatable section

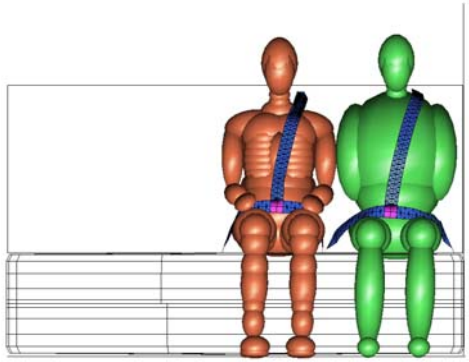


**Inflatable Seat Belt**

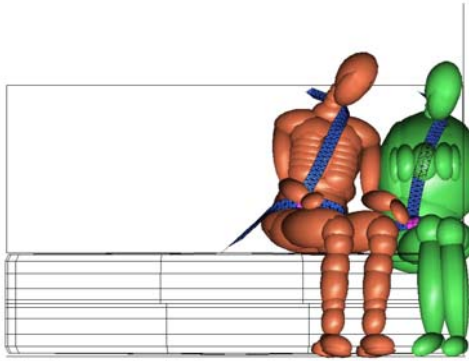
# Kinematics of ATDs with Standard 3-point Restraint System



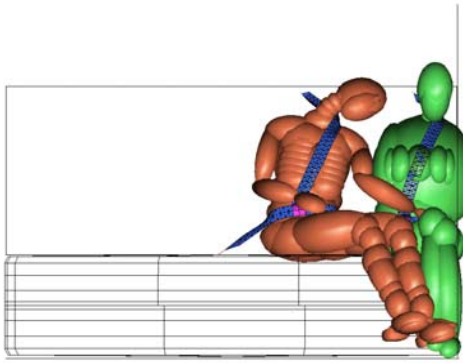
0ms



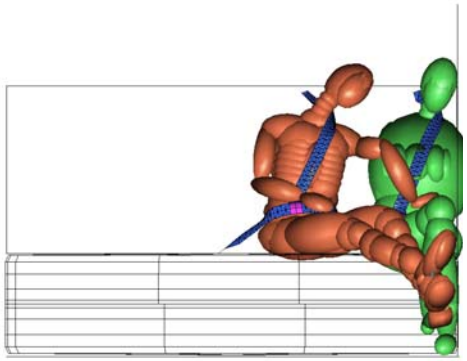
60ms



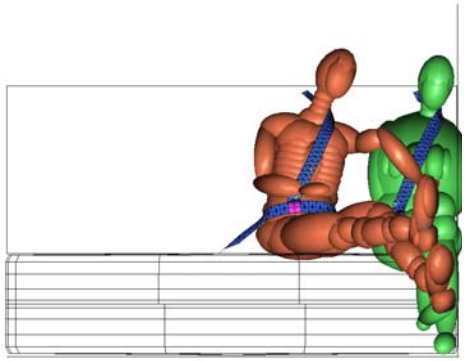
120ms



150ms

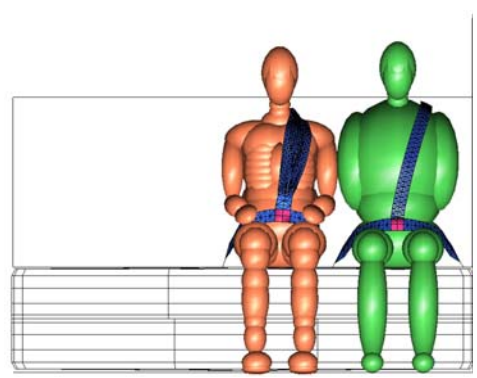


180ms

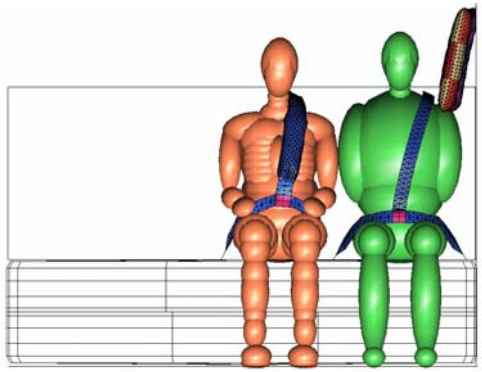


200ms

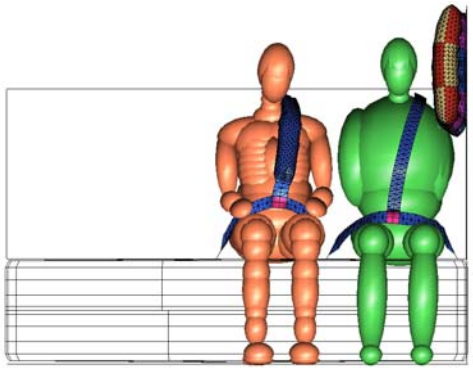
# Kinematics of ATDs with inflatable restraint system



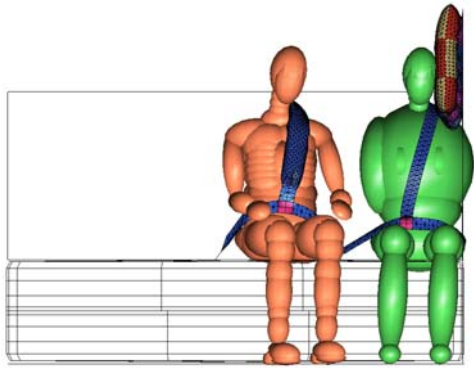
0ms



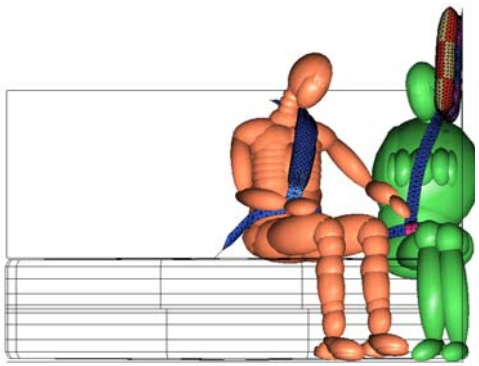
30ms



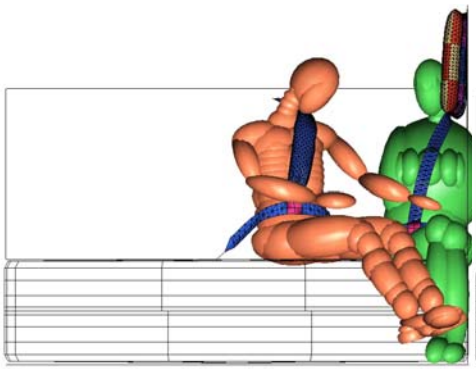
60ms



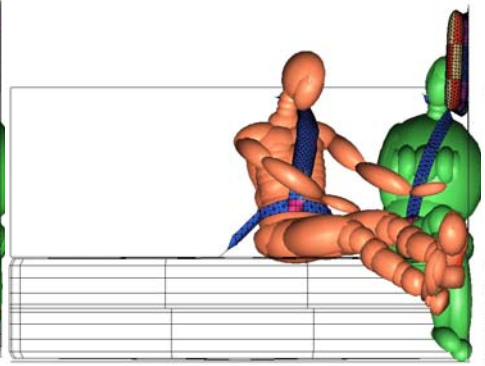
90ms



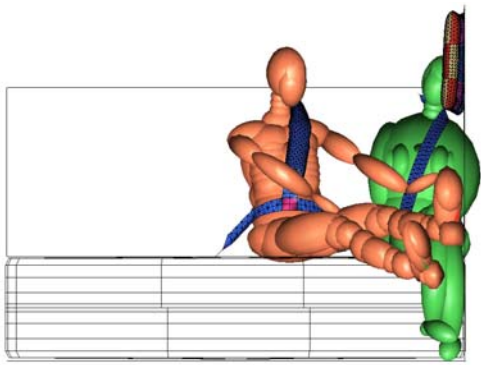
120ms



150ms



180ms



200ms

# Comparison of 3-point and Inflatable Restraint System Results

Comparison of injury parameters with & without IRS

| Injury Parameter | Peak values with 3-point restraint system | | Peak values with inflatable restraint system | |
|---|---|---|---|---|
| | **FSID** | **HIII** | **FSID** | **HIII** |
| ***Neck Loads*** | | | | |
| Axial Load Fz | 451.7 | 417.0 | 212.7 | 165.2 |
| Lateral Bending Moment Mx | 840.2 | 755.2 | 299.8 | 376.1 |
| Lateral Shear Load Fy | 332.0 | 297.9 | 189.5 | 205.6 |
| *Nij* | **2.02** | **1.82** | **0.75** | **0.88** |
| ***Accelerations (g's)*** | | | | |
| **TTI** | 55.6 | | 55.2 | |
| Pelvic acceleration | 40.9 | | 43.8 | |

# Conclusions

- Research was conducted to examine methods utilized by automotive industry to assess thoracic and pelvis injuries due to side impact accidents
- Potential applications of these methods for side-facing seats and sofas in civil aircrafts was investigated
- Limiting acceleration and compression based criteria seem to require different seat design requirements
- Limiting acceleration based criteria:
  - Is sensitive to relative velocity of impact (distance to barrier)
  - Is sensitive to stiffness of the object impacted
  - Optimum distance of 12-in or less brings TTI and Pelvic acceleration below the threshold
  - Padding reduces the TTI and pelvic accelerations
  - A seat design placing occupant closer to the barrier is desirable

# Conclusions (Cont'd)

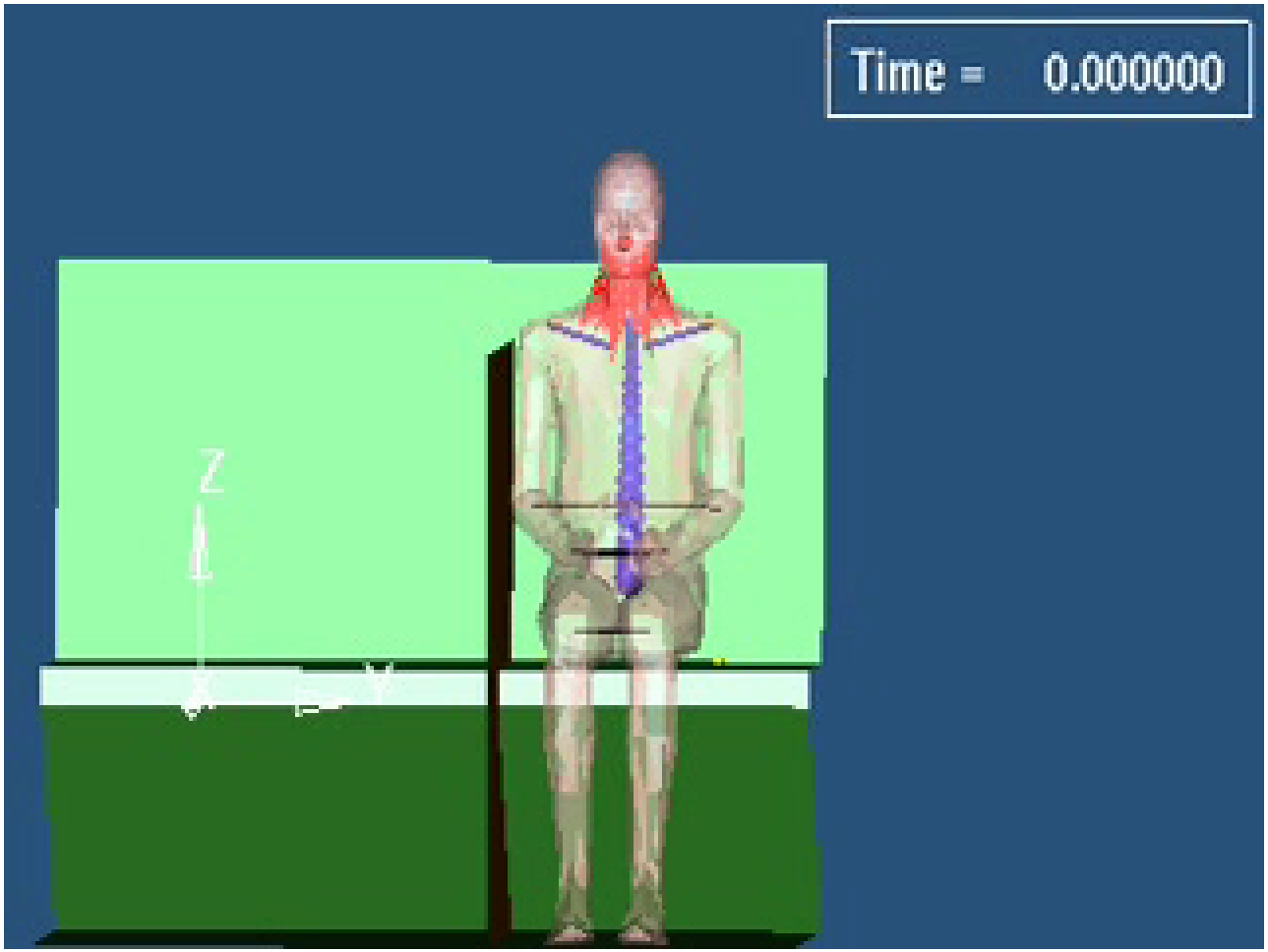
- Limiting Compression based criteria
  - Is sensitive to energy transmitted to rib cage
  - Padding on the barrier showed no significant effect on deflections
  - Avoidance of contact may be the only effective means
- When H-II ATD was placed aft of the SID or EuroSID-1
  - Acceleration and compression based criteria tended to be somewhat higher
  - Attempts to quantify the effects of body-to-body contact were not conclusive
- HIC in most cases exceeded the threshold. For providing equivalent level of safety, this needs to be addressed
- When acceleration based criteria are only desired, SID is recommended as it provides data on worst-case scenario
- When acceleration and compression based criteria are desired, EuroSID-1 is recommended because of its durability, repeatability and is capable of measuring all of the desired injury criteria

# Conclusions (Cont'd)

- Body-centered belt restraint prevented the ATD's from making significant contact to barrier or to each other
- A proposed lateral neck injury criteria Nij were evaluated in this study
  - Based on this study, neck injury could be very severe in lateral impacts in aircraft accidents
  - Inflatable restraint system might reduce the neck injury considerably
  - Other measures, such as head brace that restricts the motion of the head sideways, need to be investigated
- The proposed neck injury criteria needs to be studied further
- Cadaver tests are currently being conducted for further evaluation of the proposed Nij criteria at Wayne State University and TNO under the direction of FAA

# Sample of SFS Cadaver Testing Performed by FAA/TNO/Wayne State University

# Head and Neck Modeling of the Cadaver Test by TNO



# *Thank You*