

# Assessment of Injury Potential in Aircraft Side-Facing Seats Using the ES-2 Anthropomorphic Test Dummy

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Federal Aviation  
Administration



# Background

- **Occupant injury assessments found in dynamic seat testing requirements focus on forward and aft-facing seats.**
- **Current FAA policy on side-facing seats cites injury assessments based in part on Federal Motor Vehicle Safety Standards (FMVSS)**

# Background

- **Advanced means of assessing injuries in side impacts have been developed for application to motor vehicles.**
  - Test dummies with improved biofidelity
  - More specific prediction of injury
- **Inflatable restraint systems now available to potentially mitigate injuries in side-facing impacts.**

# Project Goals

- **Conduct a project to evaluate the injury risk presented by a typical side-facing seat configuration using the state-of-the-art methods.**
- **Assess the potential for injury mitigation provided by inflatable restraint systems.**

# Project Tasks

- **Conducted dynamic tests with typical aircraft side-facing seat configurations using the ES-2 ATD.**
  - ES-2 ATD cited in proposed automotive requirements
  - 44 ft/s 16 G (Part 25) test condition (used to allow comparison with previous studies)
  - Rigid seat used for repeatability

# Project Tasks

- **Conducted dynamic tests with typical aircraft side-facing seat configurations using the ES-2 ATD (continued).**
  - Seat and restraint configuration based on survey of leading seat manufacturers
    - Rigid seat configuration reflected the pertinent reported dimensions
    - Three point (body-centered) restraint system
  - Seating Scenarios
    - Next to a rigid wall (full body support)
    - Center occupant of a multiple-place couch
    - Next to an armrest

# Project Tasks

- **Evaluated the potential for injury using current, proposed, and preliminary injury criteria.**
  - 14 CFR 25.562
    - Head Injury Criterion (HIC)
    - Shoulder Belt Tension
  - FMVSS-214
    - Thoracic Trauma Index (TTI)
    - Pelvis Acceleration
  - EU 96/27/EC
    - Viscous Criterion ( $V^*C$ )

# Project Tasks

- **Evaluated the potential for injury using current, proposed, and preliminary injury criteria (continued).**
  - Proposed FMVSS-214 (Notice of Proposed Rulemaking)
    - T-12 (chest) Acceleration
    - Rib Deflection
    - Abdominal Forces
    - Pubic Force



# Project Tasks

- **Evaluated the potential for injury using current, proposed, and preliminary injury criteria (continued).**
  - FMVSS-208
    - Neck Forces and Moments
    - Preliminary Lateral Nij
  - Research Criteria
    - Neck Bending Angle
    - Femur Twisting Moment
    - Belt Impingement on Neck



# Project Tasks

- **Evaluated the ES-2 ATD's functionality when used in the aviation environment**
  - Interaction with restraints
  - Durability
- **Investigated test methods unique to side-facing seats**
  - Seating methods for consistency

# Project Tasks

- **Evaluated the ability of inflatable restraint systems to mitigate injuries in these seating configurations**
  - Inflatable Shoulder Belt
  - Self contained crash sensor / inflation system.
  - Prototype similar to current certified systems from AmSafe



# Project Tasks

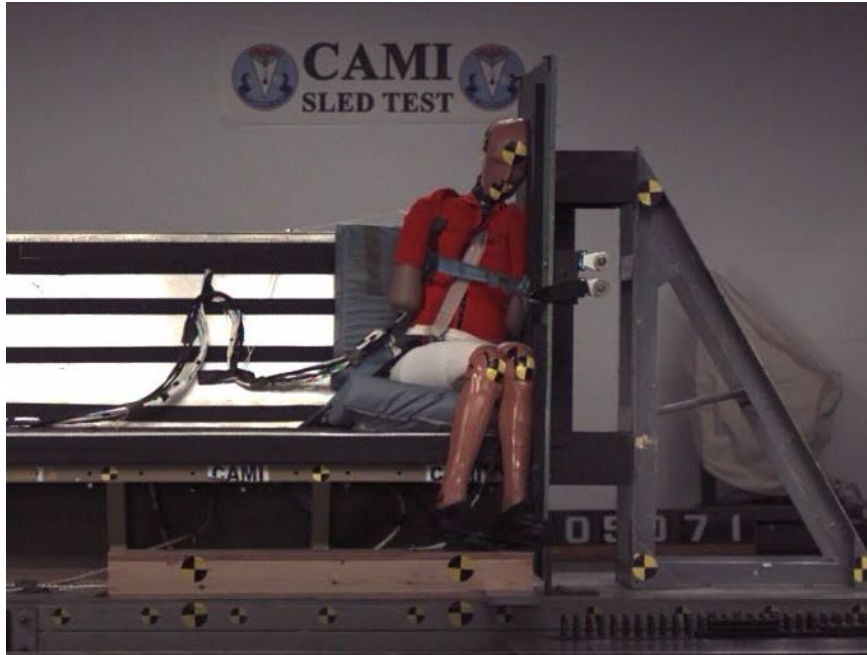
- **Test Matrix**

| Configuration | Restraint Type | ATD Type  | Test Number |
|---------------|----------------|-----------|-------------|
| Center        | Conventional   | ES-2      | A05066      |
|               |                | ES-2      | A05068      |
|               | Inflatable     | ES-2      | A05067      |
|               |                | ES-2      | A05070      |
| Close Wall    | Conventional   | ES-2      | A05065      |
| Far Wall      | Conventional   | ES-2      | A05071      |
|               | Inflatable     | ES-2      | A05072      |
| Armrest       | Conventional   | ES-2      | A05075      |
|               |                | ES-2      | A05076      |
|               | Inflatable     | ES-2      | A05073      |
|               |                | ES-2      | A05074      |
|               | Conventional   | FAA H-III | A06004      |

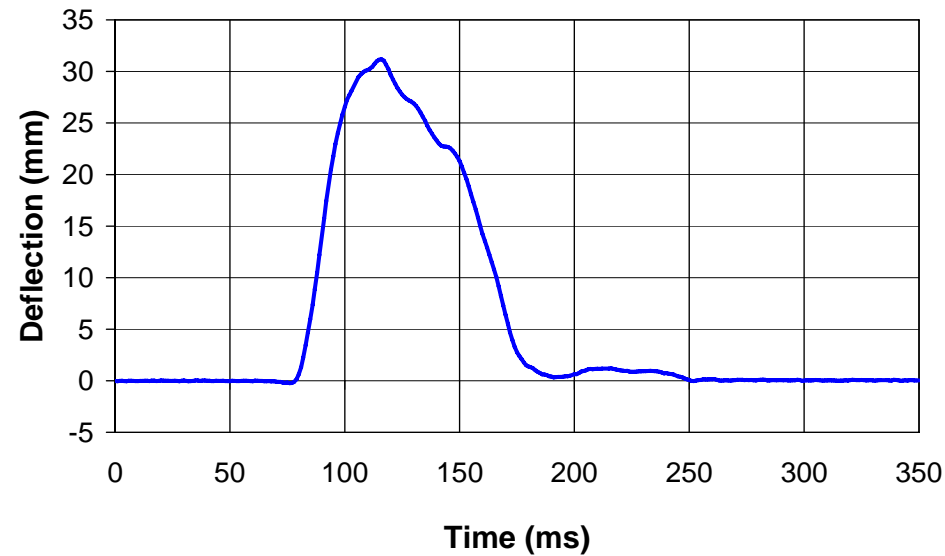
# Wall Position Conventional Restraint



# Wall Position Conventional Restraint



Upper-Rib Deflection (A05071)



# Wall Position Inflatable Restraint



# Center Position Conventional Restraint

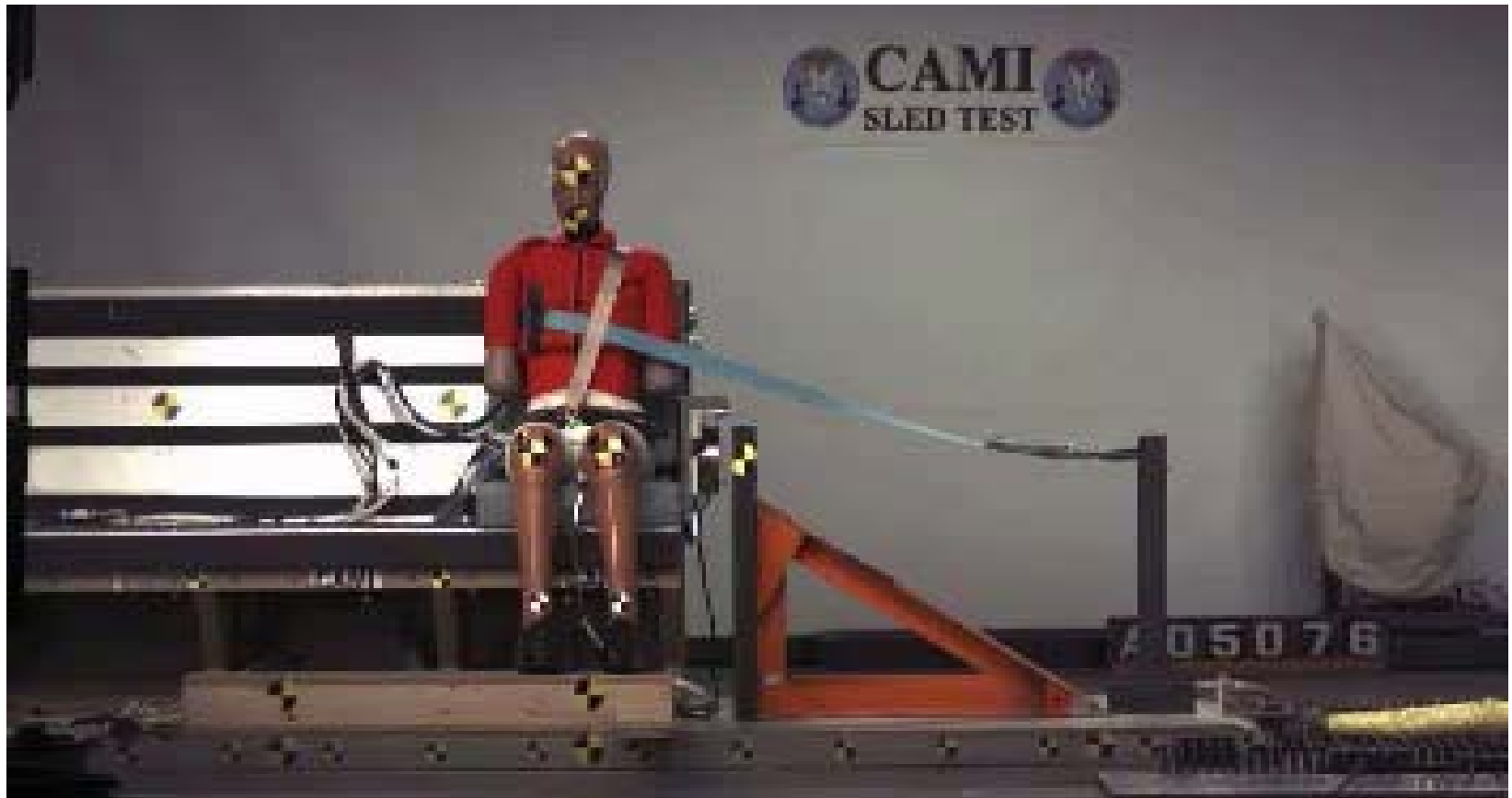




# Center Position Inflatable Restraint



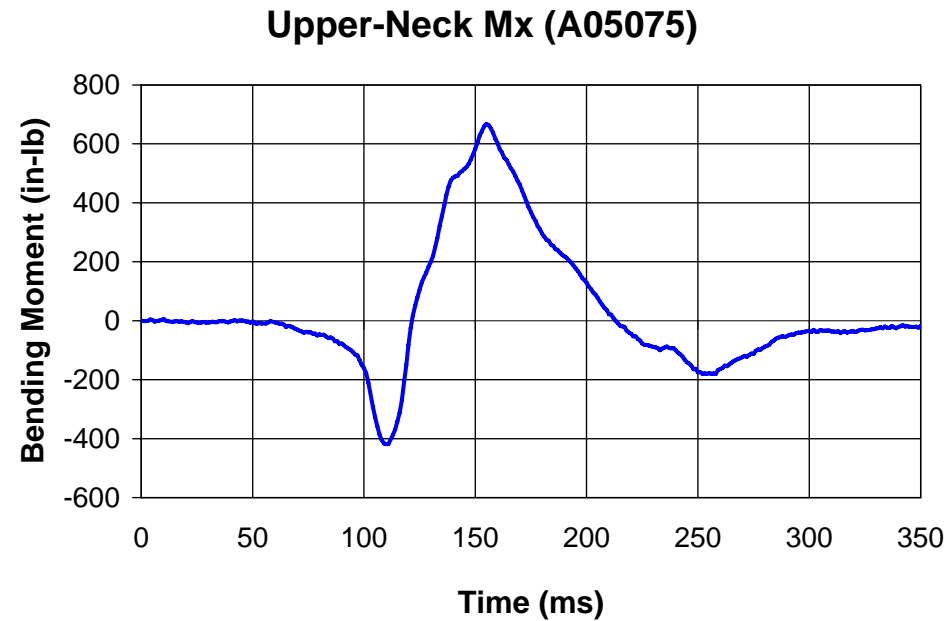
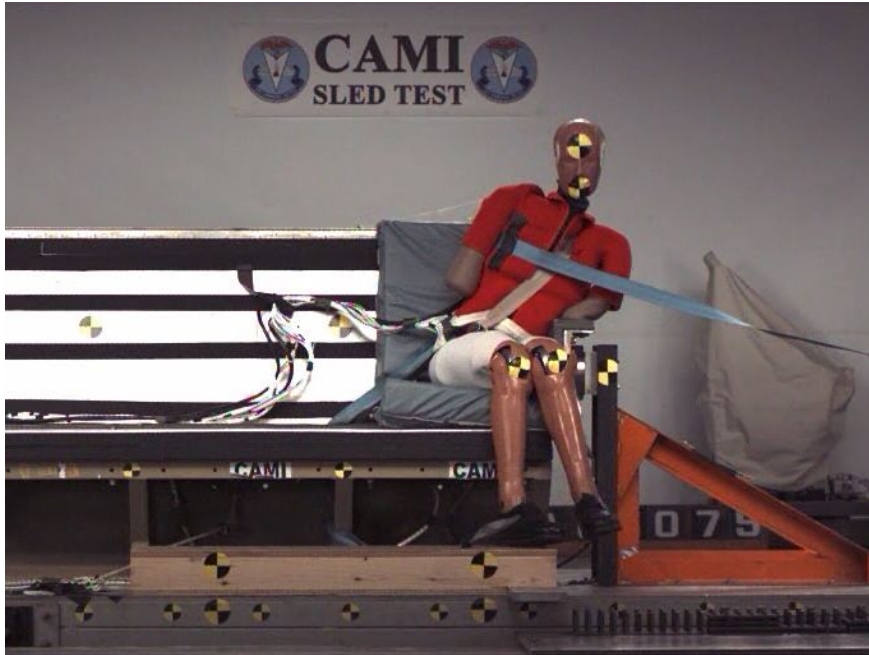
# Armrest Position Conventional Restraint



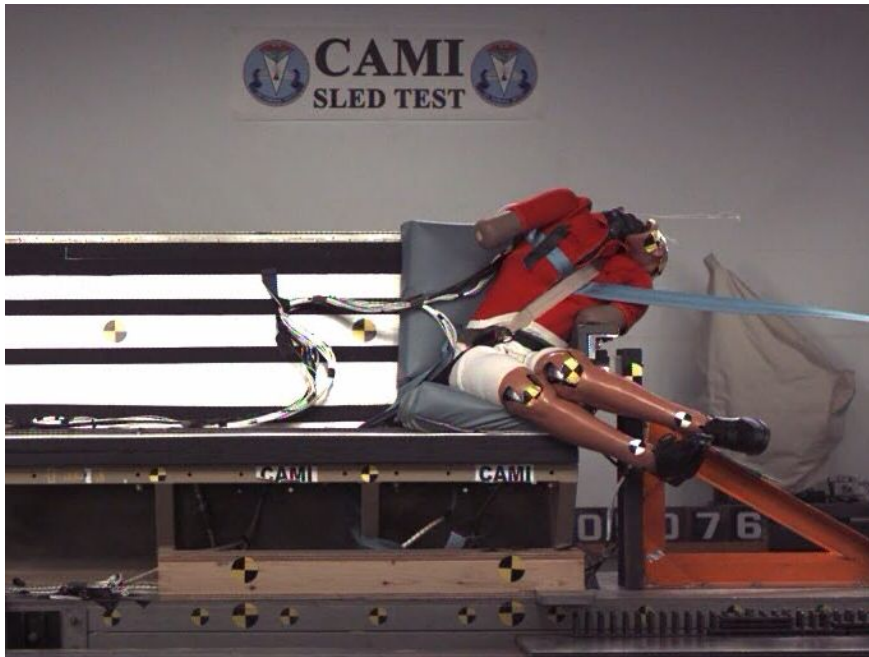
# Armrest Position Conventional Restraint



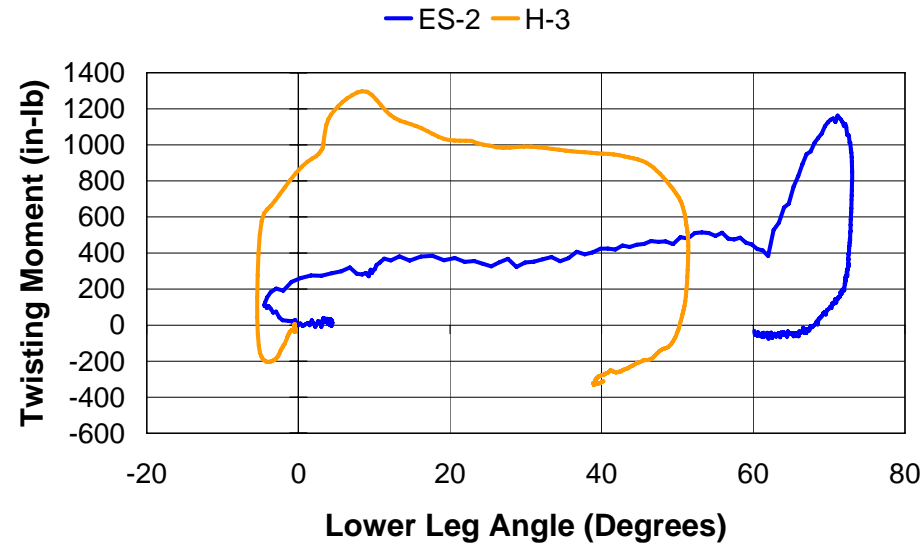
# Armrest Position Conventional Restraint



# Armrest Position Conventional Restraint



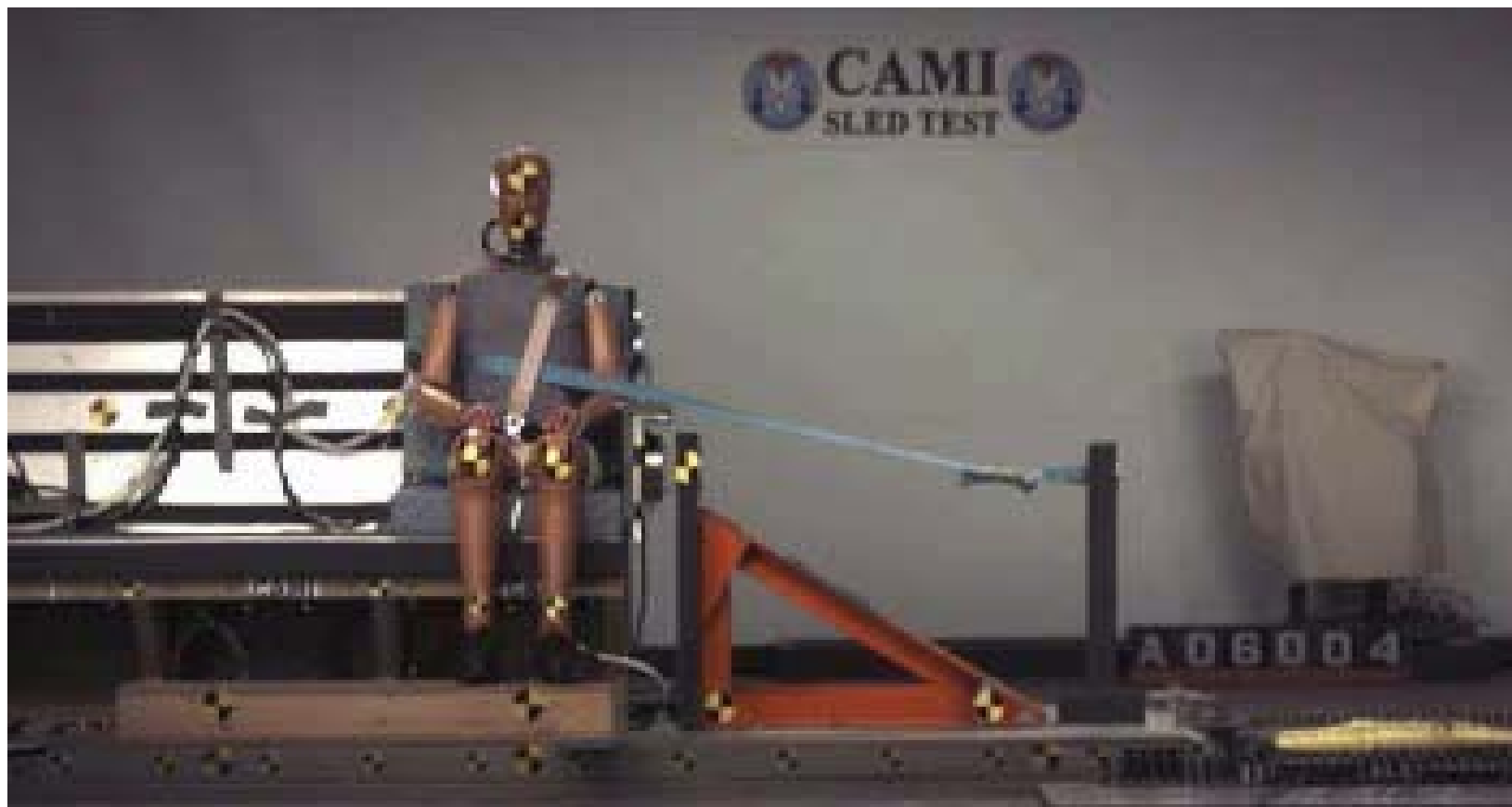
Femur Mz vs Leg Angle



# Armrest Position Inflatable Restraint

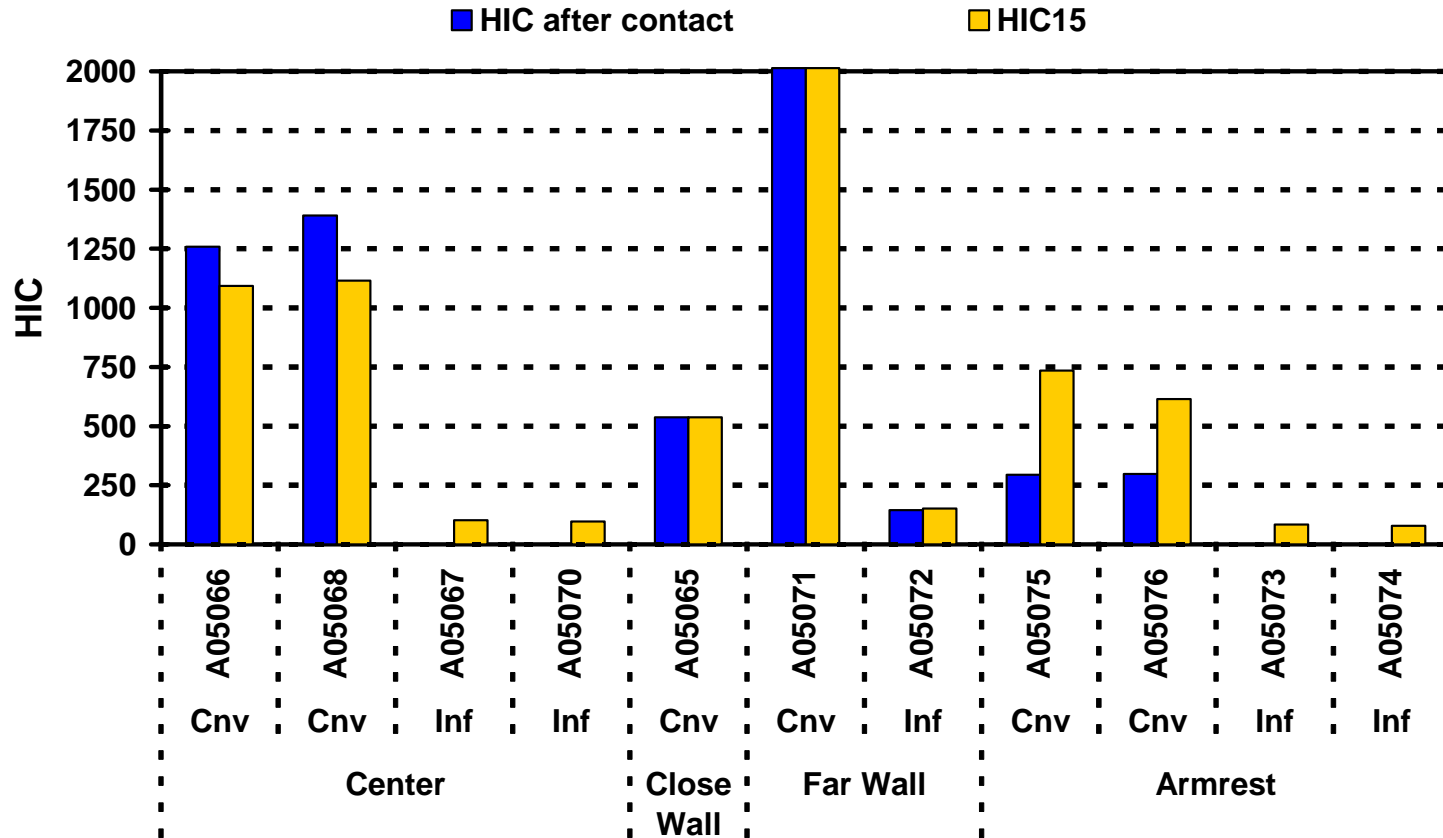


# Armrest Position H-III ATD, Conventional Restraint



# Head Injury Results

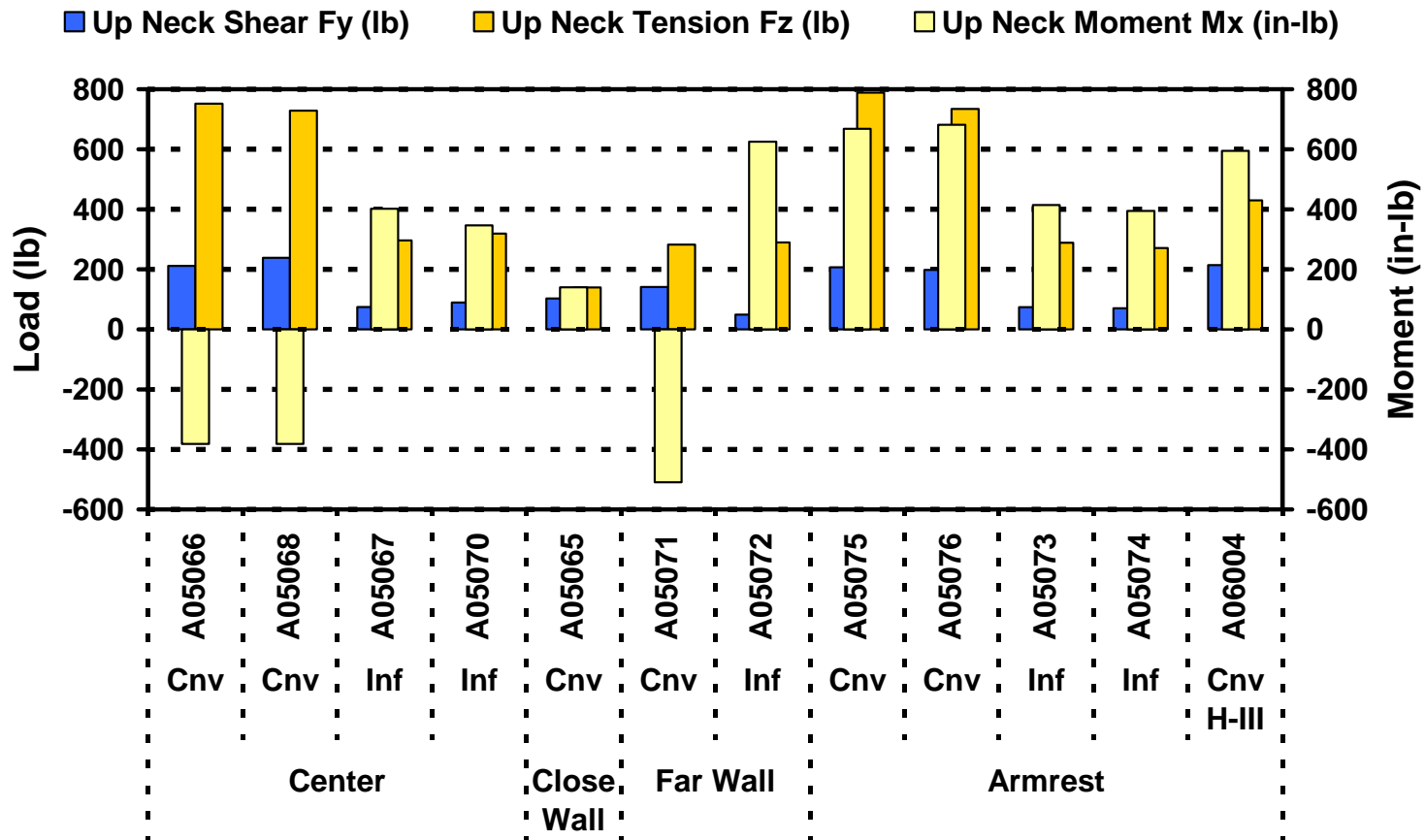
## ES2 Head Injury Response





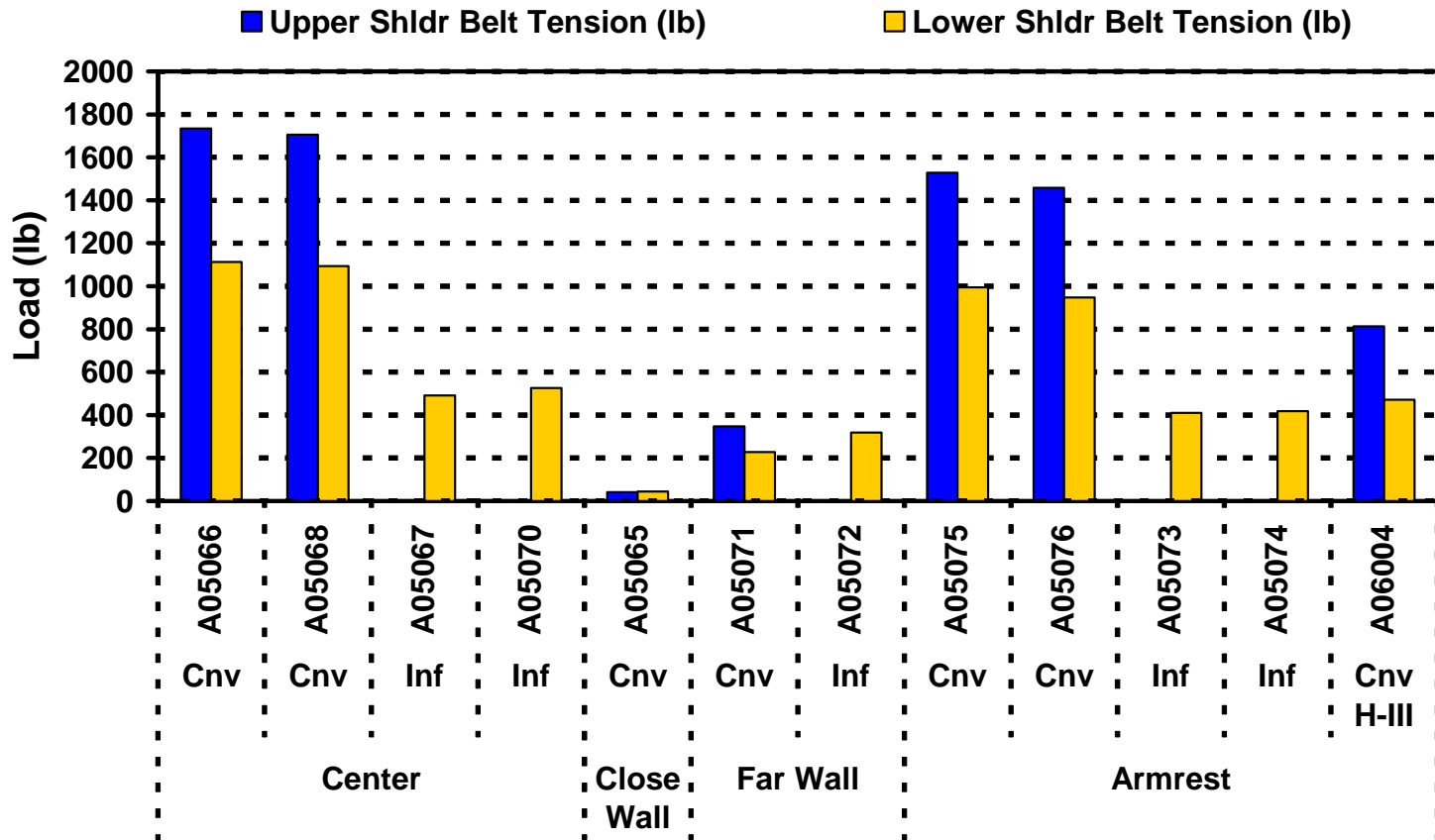
# Neck Injury Results

## Upper Neck Peak Response



# Shoulder Belt Tension Results

## Shoulder Belt Peak Response



# Conclusions

- Injury Assessment**

| Body Region | Tested Seat Configurations<br>(Conventional Restraint) |            |            |              |
|-------------|--|------------|------------|--------------|
|             | Center   | Close Wall | Far Wall   | Armrest      |
| Head        | HIC  |            | HIC        | HIC15        |
| Neck        | Nij Prelim   |            | Nij Prelim | Nij Prelim   |
| Thorax      | Belt Tension   |            | Rib Def    | Belt Tension |
| Abdomen     |  |            |            |              |
| Pelvis      |  |            |            |              |
| Leg         |  |            |            | Femur Mz     |

# Conclusions

- **Test Method Evaluation**
  - Consistent initial position achieved by preloading the lower torso during installation.
- **ATD evaluation**
  - Good overall functionality
  - Shoulder area not biofidelic
  - Neck not durable
- **Inflatable restraint evaluation**
  - Mitigated most injury risks

# Conclusions

- **Proposed injury criteria can be met using proper seat design features and advanced restraint systems.**

# Recommendations

- **Use of the ES-2 and its associated injury criteria for aircraft seat tests would allow a better assessment of the potential for injury than the current test methods.**
- **Neck injury criteria are needed to interpret the high neck loads measured.**
- **Improvements in the ES-2 shoulder's biofidelity would allow better assessment of the potential for injury caused by belt contact forces.**

# Acknowledgments

- **Co-authors:**
  - David Moorcroft, CAMI
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  - Mat Phlippines, TNO Netherlands
- **Seat survey participants:**
  - Cessna Aircraft
  - BE Aerospace
  - DeCrane Aircraft
- **Test articles:**
  - Restraint systems: AmSafe
  - Seat Cushions: BE Aerospace

# References

- **Soltis S, Frings G, van Hoof J, et al. Development of Side Neck Injury Criteria and Tolerances for Occupants of Sideward Facing Aircraft Seats. NATO/PFP; May 2003; RTO-MP-AVT-097.**
- **Green T, Barth T. Injury Evaluation and Comparison of Lateral Impacts When Using Conventional and Inflatable Restraints. Creswell, OR: SAFE Association; October 2006; E509868.**
- **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.**