Tenth Triennial International Aircraft Fire and Cabin Safety Research Conference

Occupant Injury Prediction Methods for Enhanced Passenger Safety for Range of Aircraft Seat Installation Layouts

Dr. Alan Byar | October 18, 2022 | Atlantic City, NJ
BCA Seat Dynamic Simulation

Abstract:

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Boeing Commercial Airplane (BCA)

Certification of passenger seats for installation on Boeing commercial airplanes requires compliance to 14 CFR 25.562, which includes successful dynamic testing to show that both structural and occupant injury criteria are met. Proven advanced analytical methods are used at Boeing throughout the aircraft development, design and certification process to ensure all regulatory requirements are met, and to promote passenger safety. While seat structural integrity and occupant safety have been historically assured through physical certification testing, the same level of passenger safety might be achieved using analytical methods, due to recent advancements of modern computer modeling and simulation technology. Advisory Circular (AC) 20-146 provides the requirements and applicability of using dynamic simulation towards seat Certification by Analysis (CBA).

Dynamic simulations serve to verify structural integrity and passenger safety, as well as to improve design quality, predictability of dynamic responses, and to facilitate certification through smarter testing. Successful aircraft seat row-to-row Head Injury (HIC) and Neck Injury (Nij) compliance has in some cases taken many physical test iterations, which is time intensive, inefficient, and subject to testing variability. Both developmental and certification tests need to be repeated to account for a range of installation seat pitches, 5th, 50th and 95th percentile dummies, several required impact zones, and range of yaw angles to meet the regulatory requirements.

Use of simulation aids in understanding the occupant injury parameters, and in understanding testing variability. Use of testing devices such as the Free Motion Headform (FMH) and Pendulum provides greater degree of control in effectively predicting response of seat design for enhanced safety of passenger. Metrics-driven building block component testing and simulated row-to-row injury predictions for HIC and flailing can help with early design concept development. Simulations aid in evaluating energy absorption devices and breakaway mechanisms, and can reduce the number of testing iterations needed for design and certification.

The objective of this paper is to present potential processes and methods for injury prediction, such as use of Free Motion Headform (FMH), and which could aid in certifying the seat installation by evaluating the desired performance of the seat design. The proposed focus would be on simulation and component testing to design seats and installations that yield the required final performance outcome (HIC<1000 and Nij <1.0).

Agenda

- ATD options for human body response
- Free Motion Headform (FMH) for HIC evaluation
- Seating Configurations
- Simulations of front row 16g responses – HIC, Nij, Lumbar
  - 2 point and 3 point belts
  - With and without airbag
  - Effect of Yaw
- Summary

ATD/v-ATD and HBM:

- Conformity of test ATD is known issue (component masses, joint stiffness, wear and tear)
- ATD kinematics will influence injury response
- Higher fidelity models are available for injury response (THUMS, THOR-Test Device for Human Occupant Restraint)

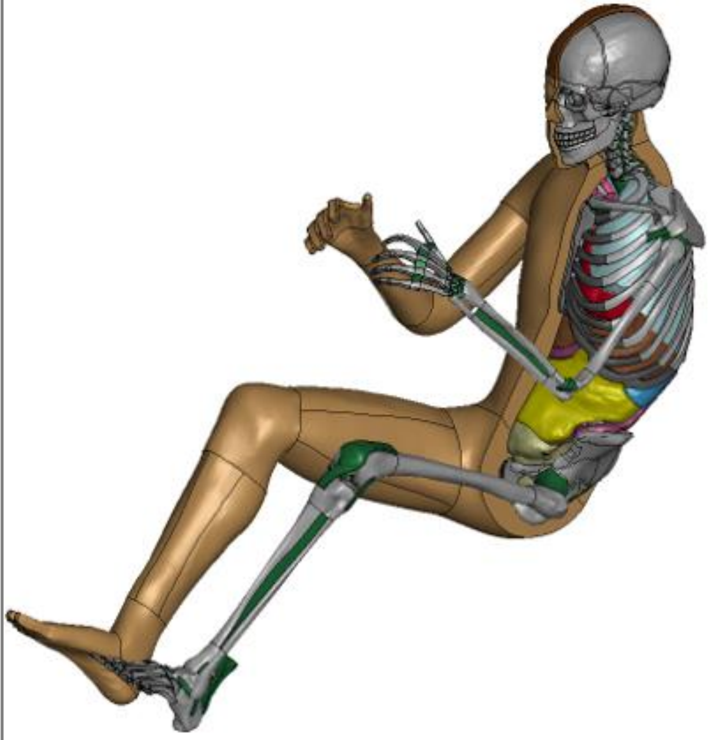
Aerospace Application

Hybrid II 50th Male

FAA Hybrid III 50th Male

ES-2re Side Impact ATD

Kinematics and Injury



THUMS (Total HUman Model for Safety)

Crash Test ATD's and Common Injury Parameters

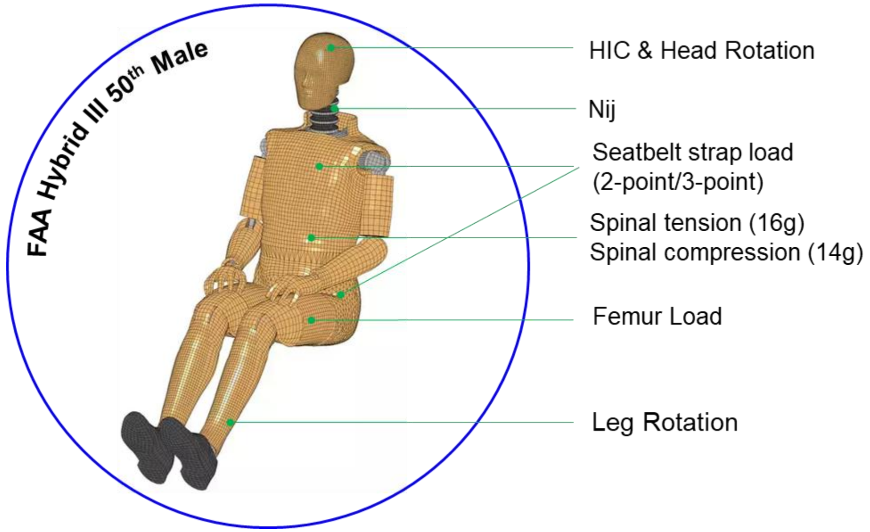
Aerospace Application

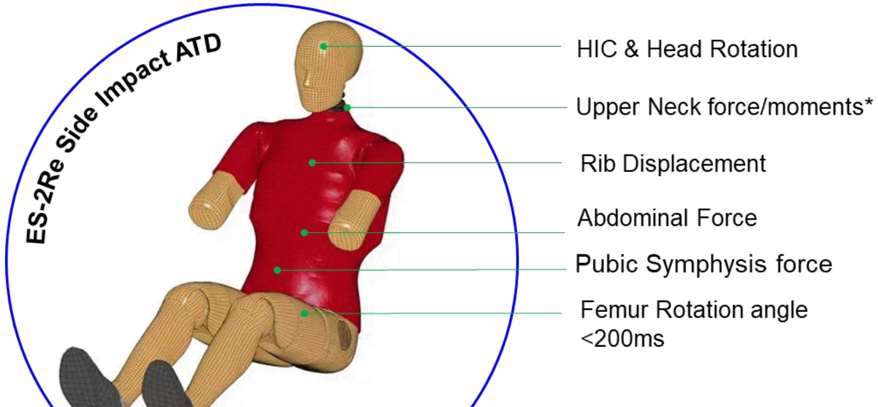
Quantitative Injury Parameters: Quantifiable

- Head Injury Criteria, HIC < 1000 & <700 (Airbag)
- Head rotation < 105 deg.
- Neck Injury Criteria (NTE,NTF, NCE,NCF), Nij < 1.0
- Spinal tension load for flailing < 1200 lb.
- Spinal (Lumbar) compression < 1500 lb.
- Shoulder belt strap load <1750 lb.
- Femur Compressive load < 2250 lb.
- Rib displacement (compression) < 1.73 inch
- Abdominal Force < 562 lb.
- Pubic Symphysis Force < 1350 lb.
- Femur rotation @ 200ms < 35 deg.

Qualitative Injury Parameters: Unquantifiable

- Neck contact/pressure load
- Upper torso restrain remain in occupant shoulder
- Lap belt must remain on occupant pelvis





* Upper Neck force/moments
Neck Tension < 405 lb.
Neck Compression < 405 lb.
Neck Bending < 1018 in-lb
Neck Shear < 186 lb.

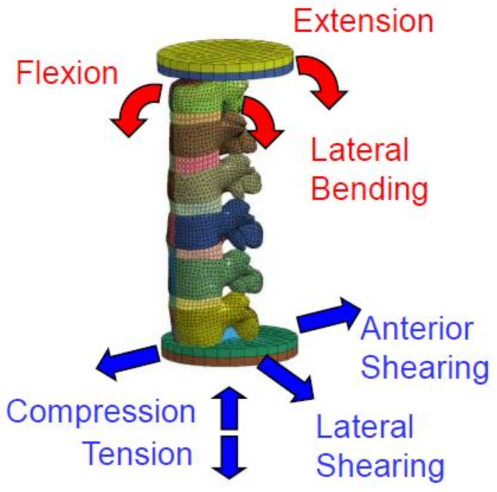
Requirements of an ATD:

1. Bio-fidelity: How trustworthy the ATD kinematics a human being
   - Kinematic biofidelity
   - Dynamic compliance biofidelity
   - Injury measure biofidelity
2. Repeatability: How well an ATD will measure the same parameters for repeated set of identical test conditions
3. Reproducibility: How well two identical ATD produce the same measured parameter/values when exposed to same test condition.
4. Durability: an ATD must not be destroyed or degraded by an impact test.
5. Calibration Standards:
   - Current calibration practice at 1 year intervals

v-ATD Vs. HBM: Kinematic bio-fidelity

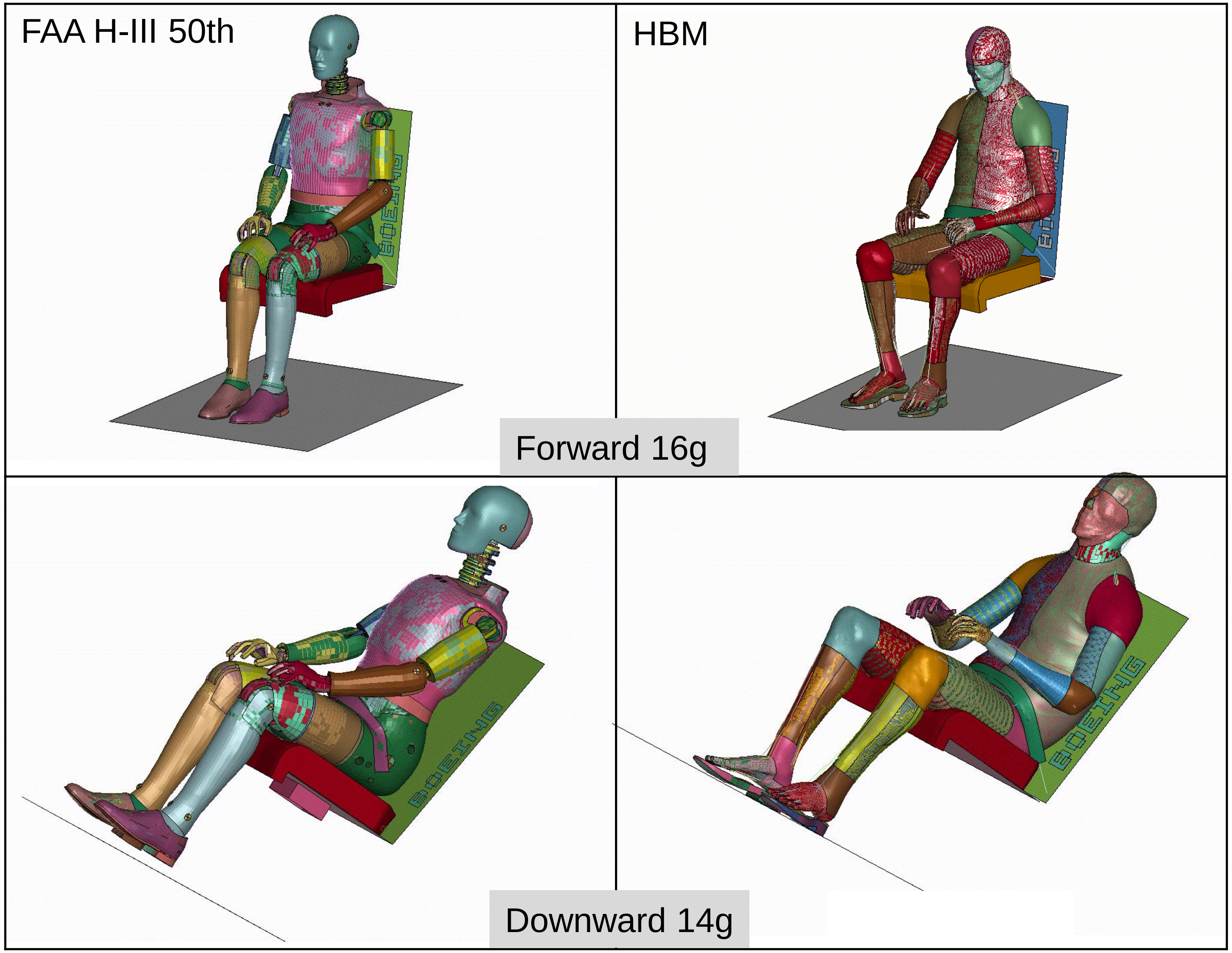
- Kinematic bio-fidelity
- Dynamic compliance bio-fidelity
- Injury measure bio-fidelity

Dynamic compliance bio-fidelity:



(a) Loading conditions

Lumbar Spine Validation Example

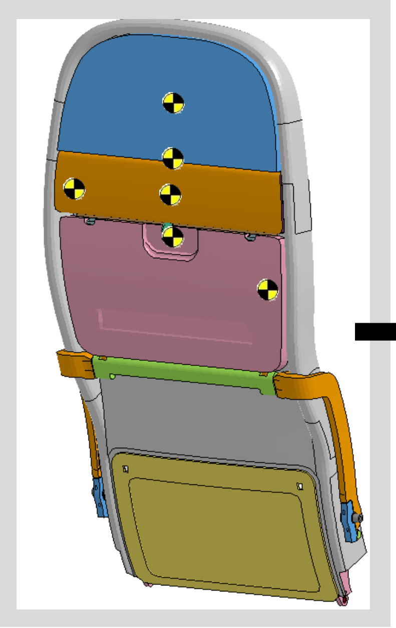


Free Motion Headform: Use to supplement ATD seat testing

- Use of FMH greatly reduces test variability
- Variability in impact velocity with ATD (dependent on hand-seatback interaction)
- Variability in impact location and impact angle with ATD
- Variability in ATD initial contact (such as chin, top of head) – HIC assumes impact on forehead
- Short duration impact with FMH better aligns with HIC assumption of short impact/constant mass

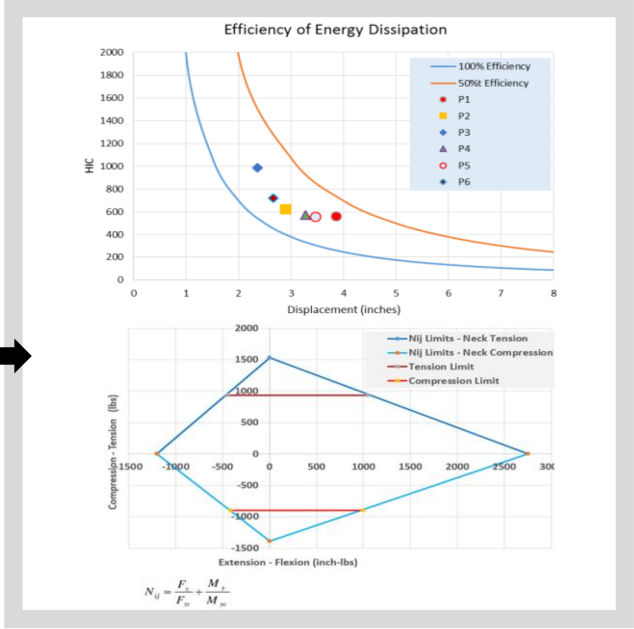
Aerospace Application

Characterize seatback response at multiple locations



Modeling & Simulation

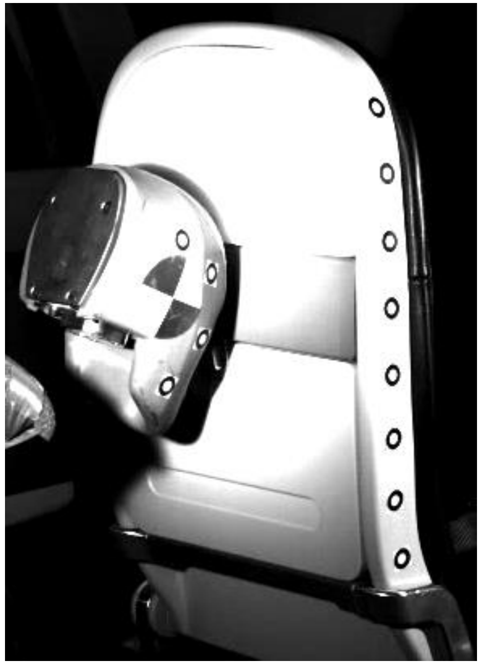
FMH Model Validation



Seatback HIC& Nij Characteristic

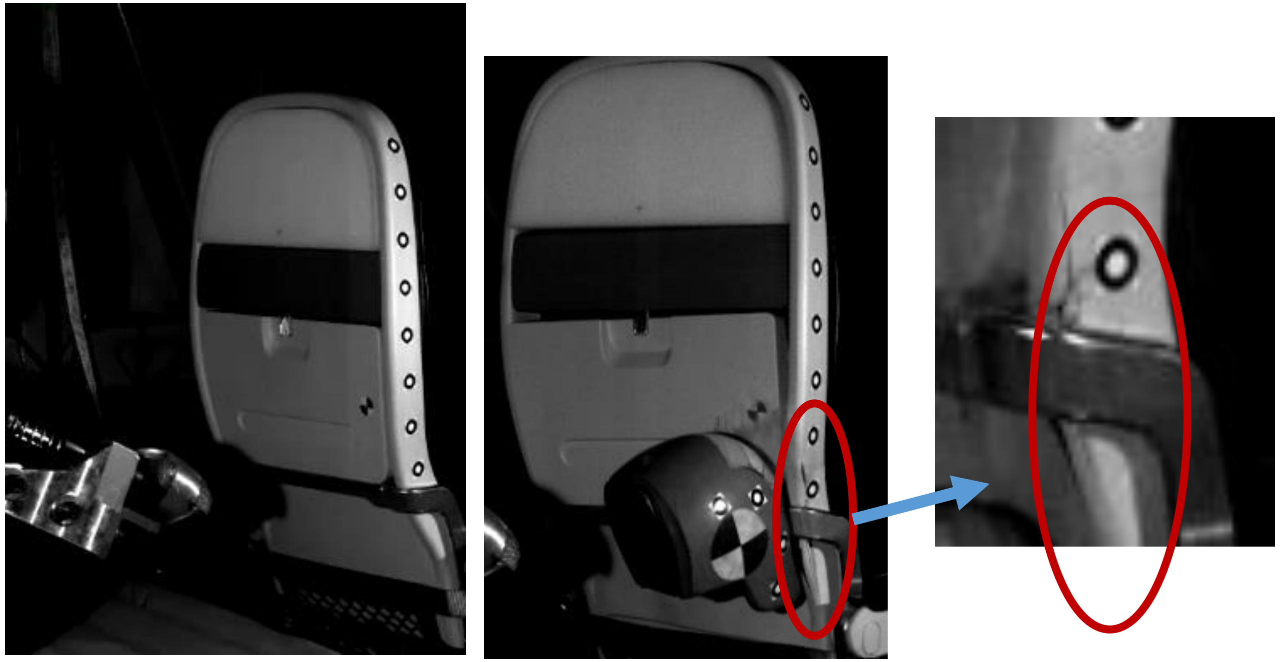
Free Motion Headform (FMH)

- FMH can be used to characterize seatback for range of impact velocities



FMH – prior to impact

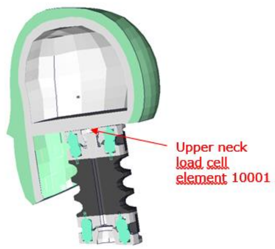
FMH impact center location

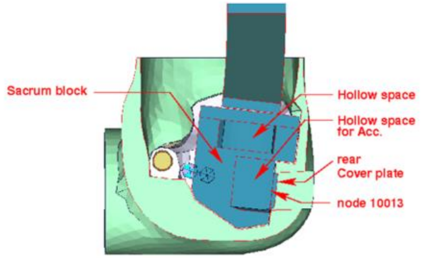


- FMH impact lower right
- Impact location can be specified
- No trial/error or approximations by region (missing/hitting frame makes significant different in response)
- FMH impact on seat frame shows effect of composite failure
- Partial impact on frame also shows effect of minor changes in impact location

Occupant Injury Criteria:

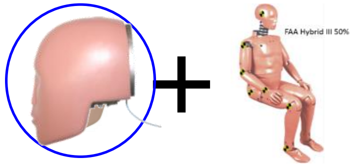
- Head Injury Criteria (HIC)
- Neck Injury Criteria (Nij)
- Spinal Tension for flailing
- Chest compression
- Leg rotation
- Head rotation
- Head-Knee impact





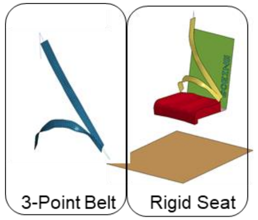
Test Devices / Approach:

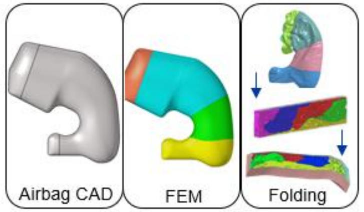
- ATD’s: H-II, H-III, Es-2Re
- FMH, Pendulum (Design)

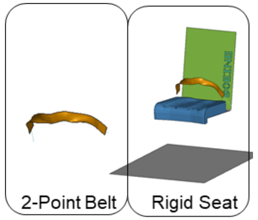


Restraint System:

- Active: Seatbelt
- Passive: Airbag system





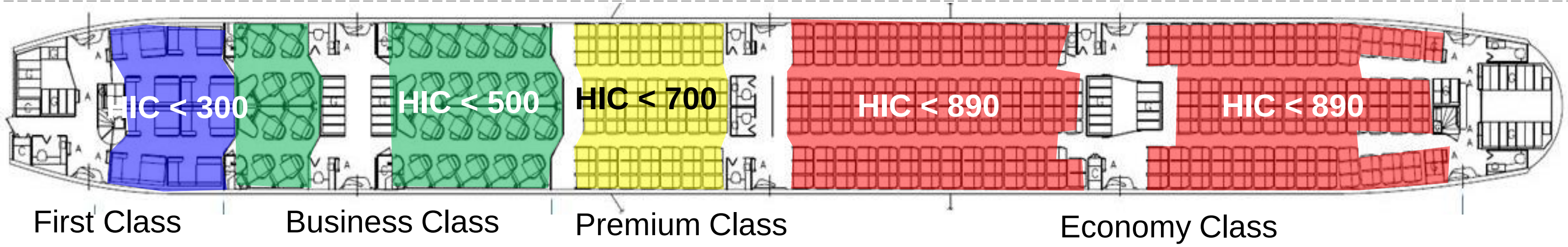


Seat Types:

- Economy/Premium
- Business
- First class

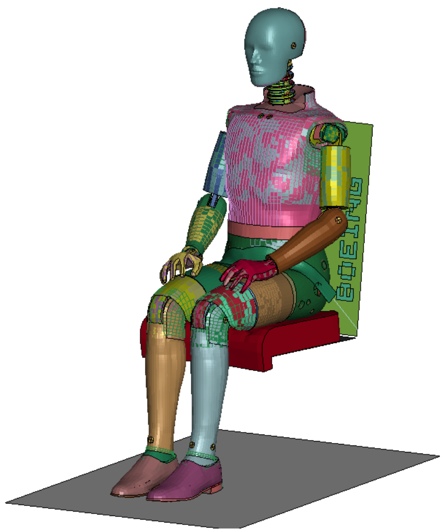
Seat Installation: LOPA

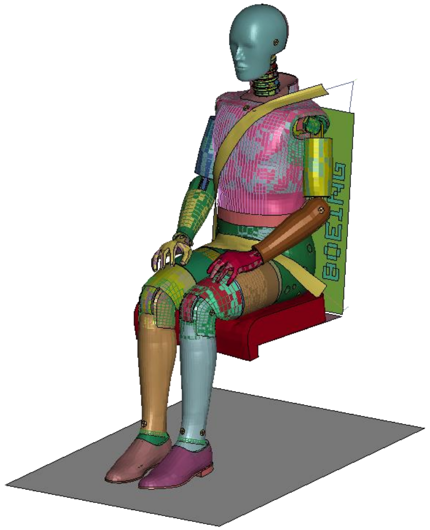
- Forward facing
- Oblique facing
- Side facing

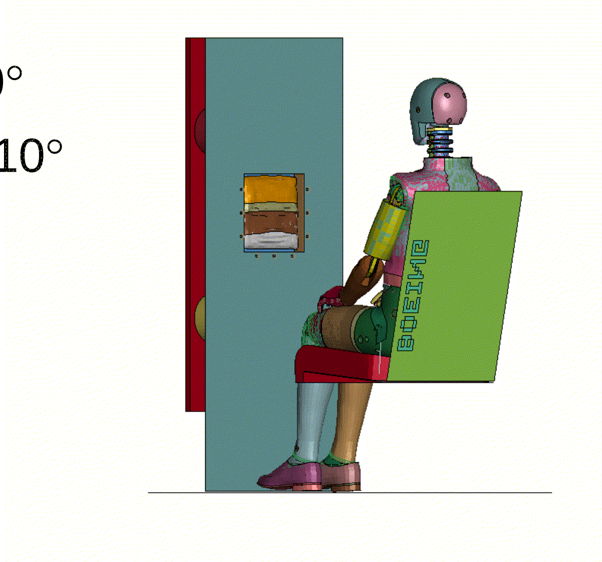


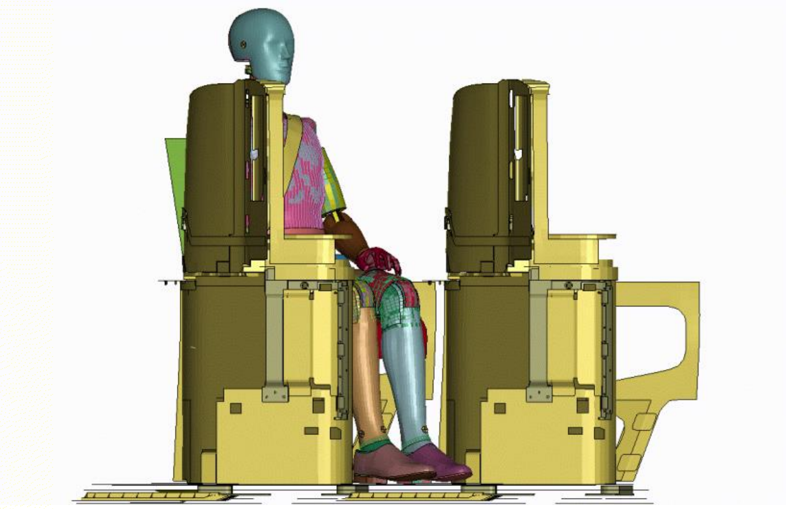
Occupant Injury Assessment Study – Use rigid seat

1. Standard 2-point belt
   a. Yaw angle -0°
   b. Yaw angle - 10°
2. Standard 3-point belt
   a. Yaw angle 0°
   b. Yaw angle 10°
3. Standard 2-point and 3-point belt with Airbag
   a. (2-point/monument airbag) Yaw angle 0°
   b. (2-point/monument airbag) Yaw angle 10°
   c. (3-point/seatbelt airbag) Yaw angle 49°±10°









Boeing Internal Research Findings and Risk

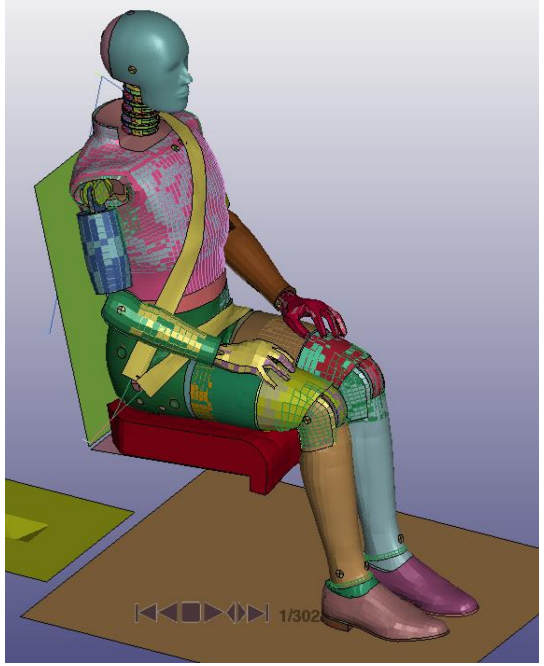
- For cases considered, acceptable response only seen with airbag
- 3 Point belt leads to unacceptable neck response, especially with yaw condition to right (away from slipring)
- Simulation provides method of quickly assessing multiple impact conditions

Overall	Configuration	Moment in-lbs	Load lbs	Axial Limit	Nij	Spinal Tension	HIC	Notes
fail	2pt-belt only + Yaw 0°	-650.5	863.3	937	1.11	2553.84	11890	Flailing/ head hits both legs
fail	2pt-belt + Yaw 10°	-539.9	750.9	937	0.94	2544.85	16760	Flailing/ head hits one leg
pass	2pt-belt + airbag + Yaw 0°	649.7	177.6	937	0.66	112.41	289	no hard contact on structure
fail	2pt-belt + Yaw 0+bulkhead	-987.2	1036.4	937	1.50	1942.36	1640	head hits leg
fail	2pt-belt+ bulkhead impact	-1851.3	-984.7	-899	2.19	1436.54	5332	head hits bulkhead
fail	2pt-belt bulkhead+10°	-412.4	964.4	937	0.97	1872.67	1698	head hits leg, neck > 937 lbs
fail	3pt-belt only + Yaw 0°	304.5	1456.8	937	1.21	1103.82	153	no hard contact
fail	3pt-belt + Yaw (+) 10°	429.3	1148.8	937	1.11	1112.81	132	no hard contact
fail	3pt-belt + Yaw (-) 10°	501.8	2102.0	937	1.79	1002.65	383	no hard contact
pass	3pt-belt+ Yaw 49° + Airbag	414.4	595.1	937	0.54	409	505	Test Data/no hard contact

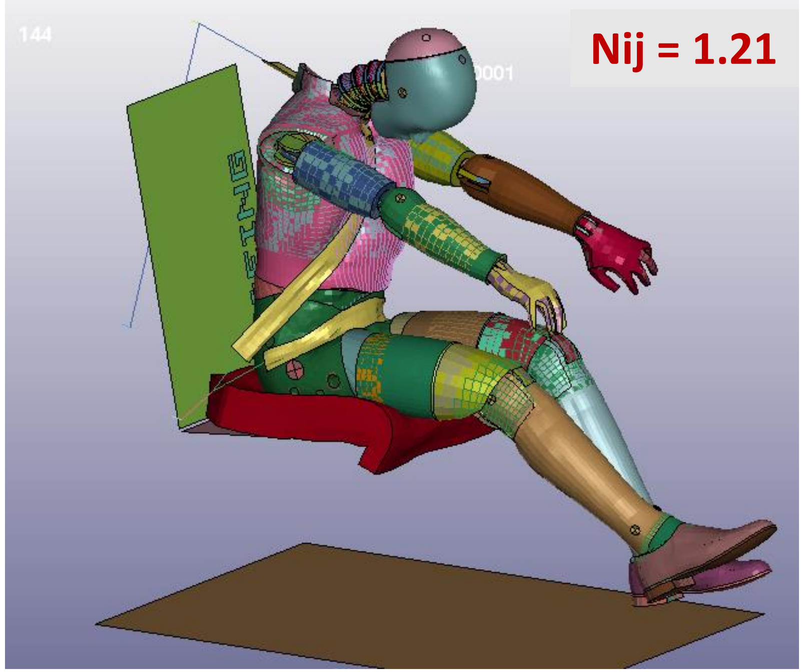
Boeing Internal Research Findings and Risk

- 3 Point belt – neck response not acceptable
- Both fail in neck tension
  - 0 Degree Yaw shows higher neck loads
  - 10 Degree Yaw to right shows significantly higher neck loads

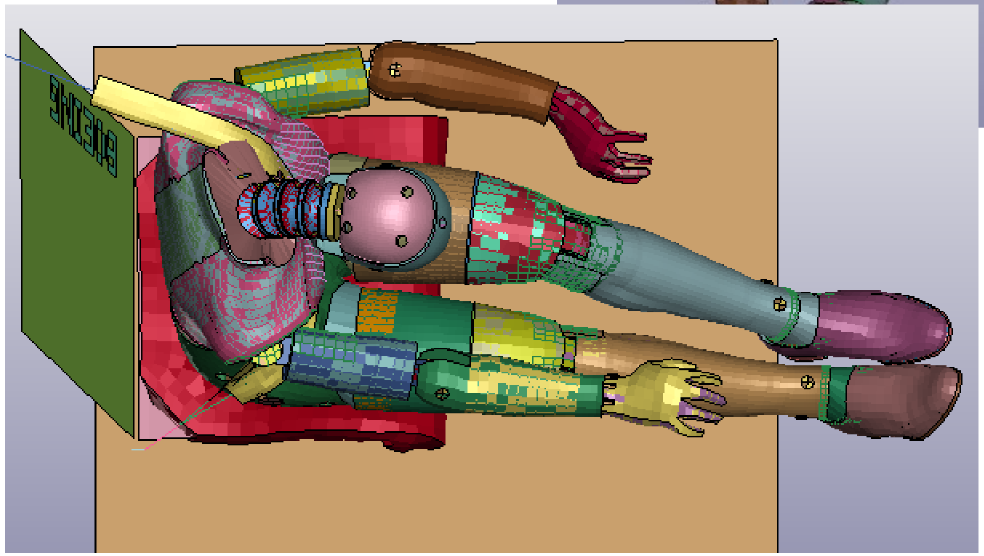
Initial Position



0 Degree Yaw

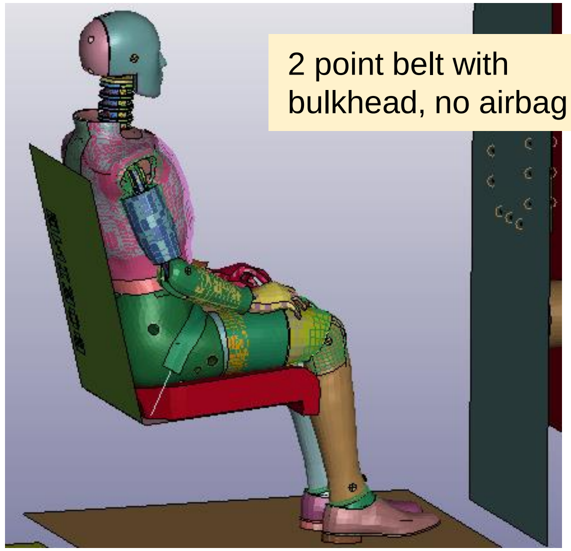


10 Degree Yaw



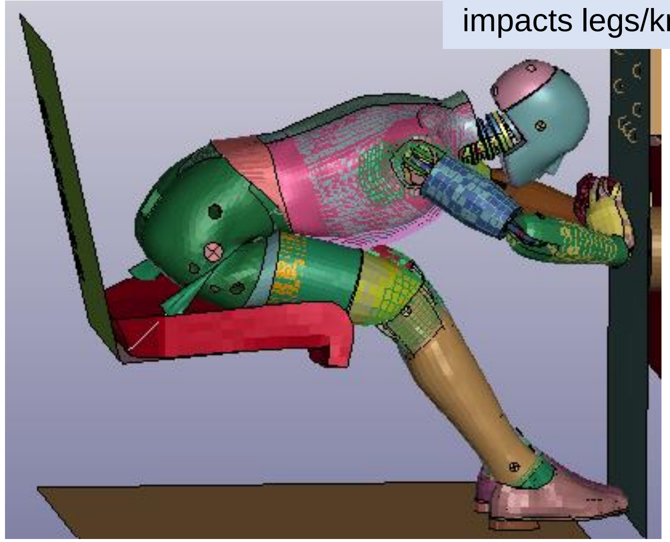
Boeing Internal Research Findings and Risk

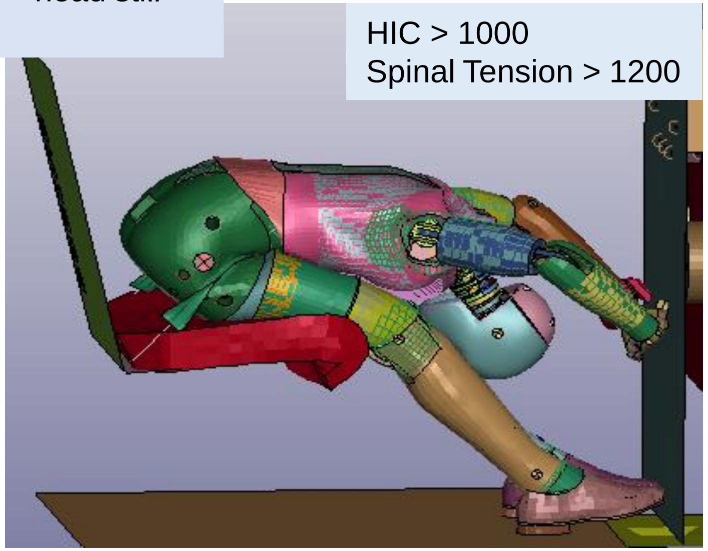
- Impact to legs occurs both with 0 degree and 10 degree yaw for front row, with and without bulkhead



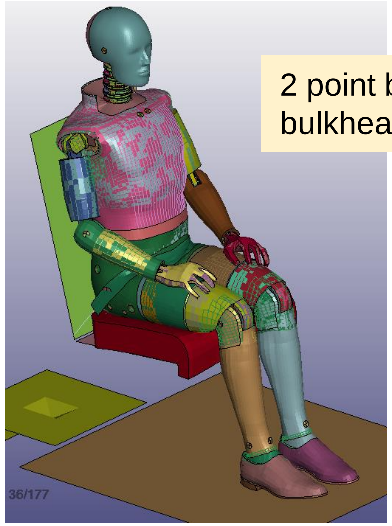
2 point belt with bulkhead, no airbag

Hands contact bulkhead – head still impacts legs/knees

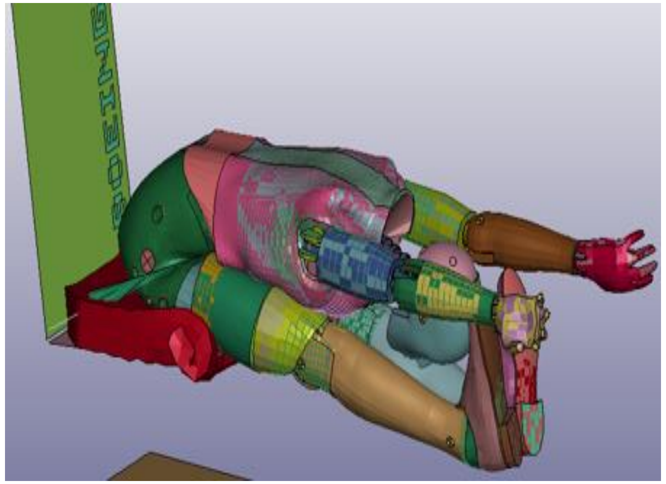


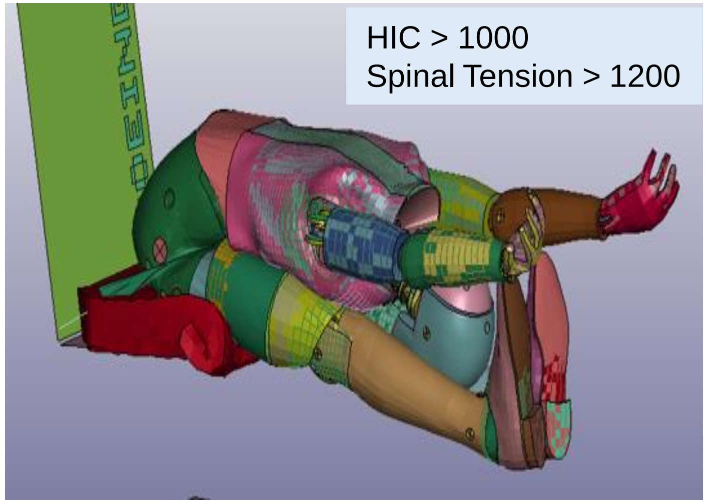


HIC > 1000
Spinal Tension > 1200



2 point belt without bulkhead

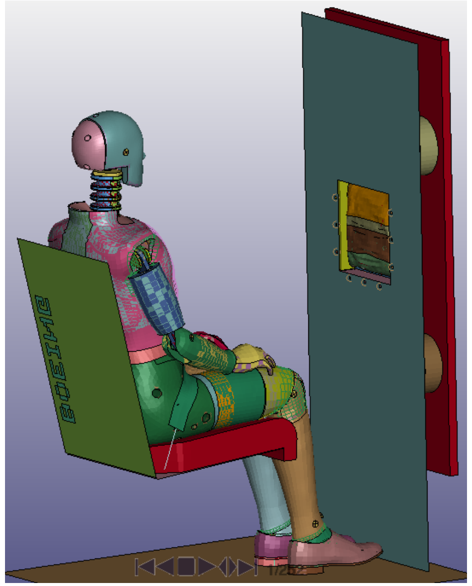


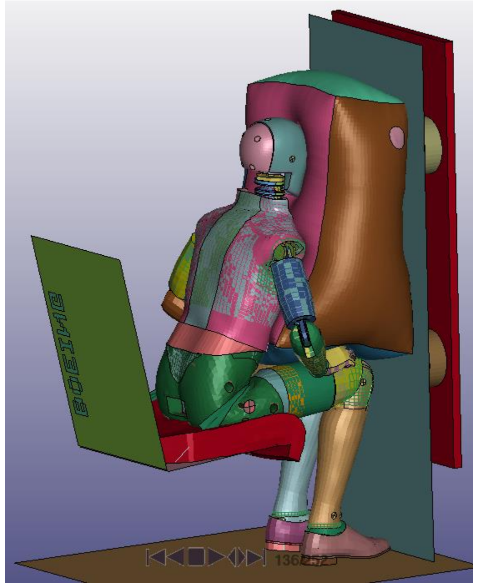


HIC > 1000
Spinal Tension > 1200

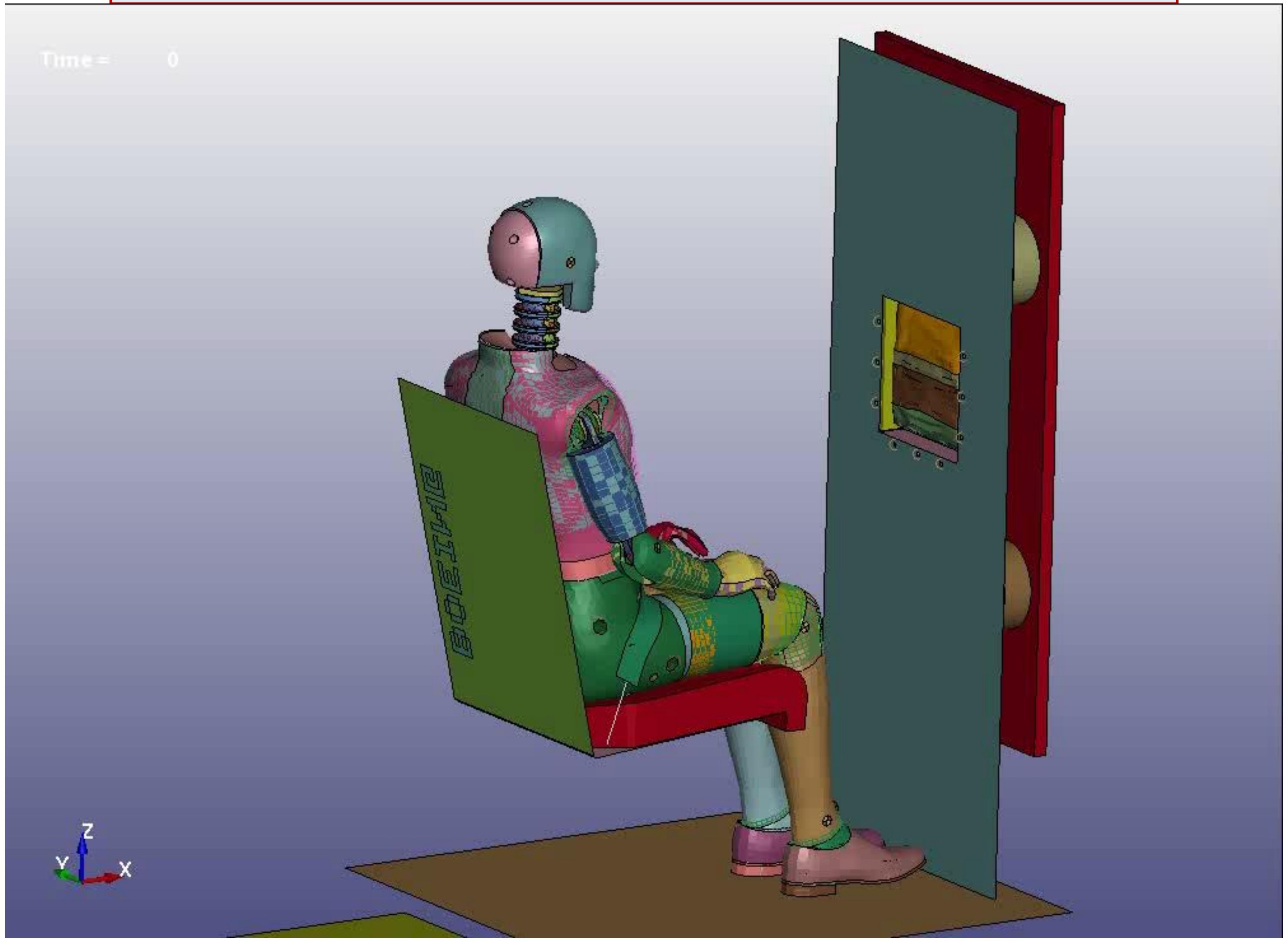
Boeing Internal Research Findings and Risk

- Airbag leads to acceptable response with 2 point belt



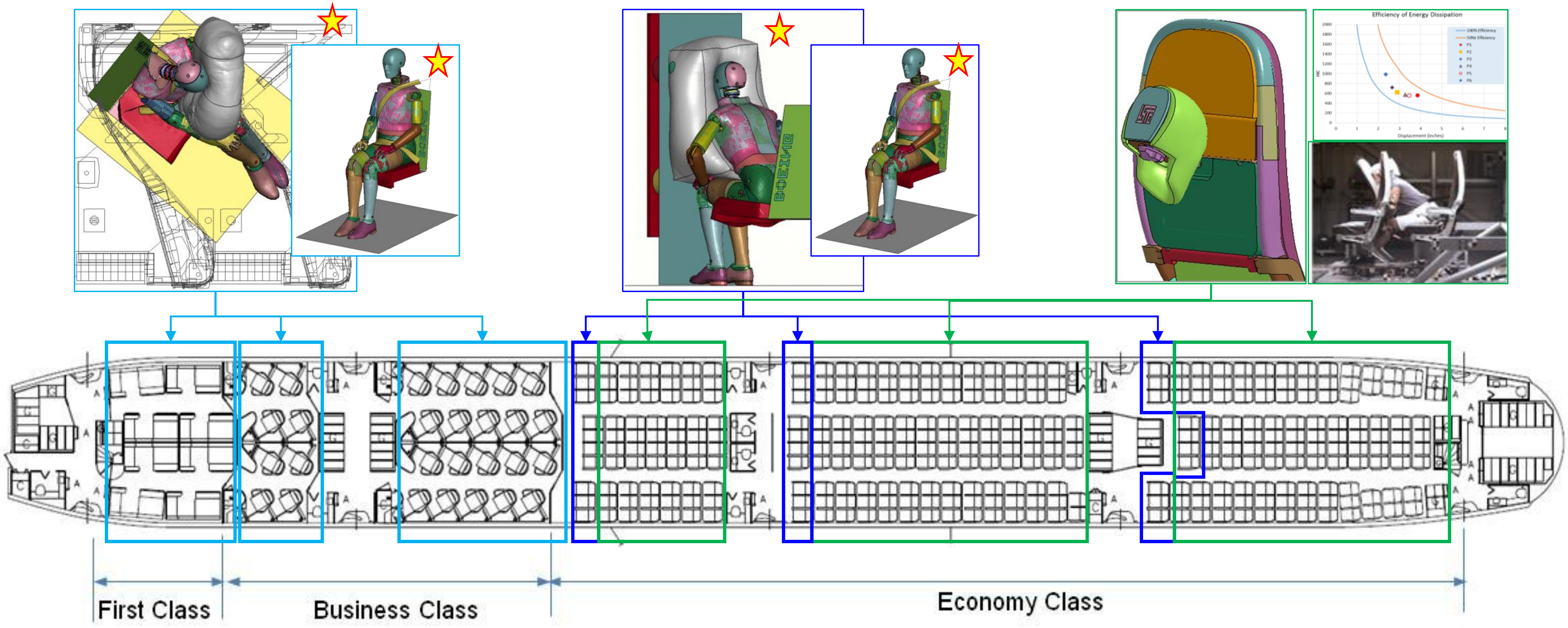


Airbag limits HIC, head motion, limits lumbar loading



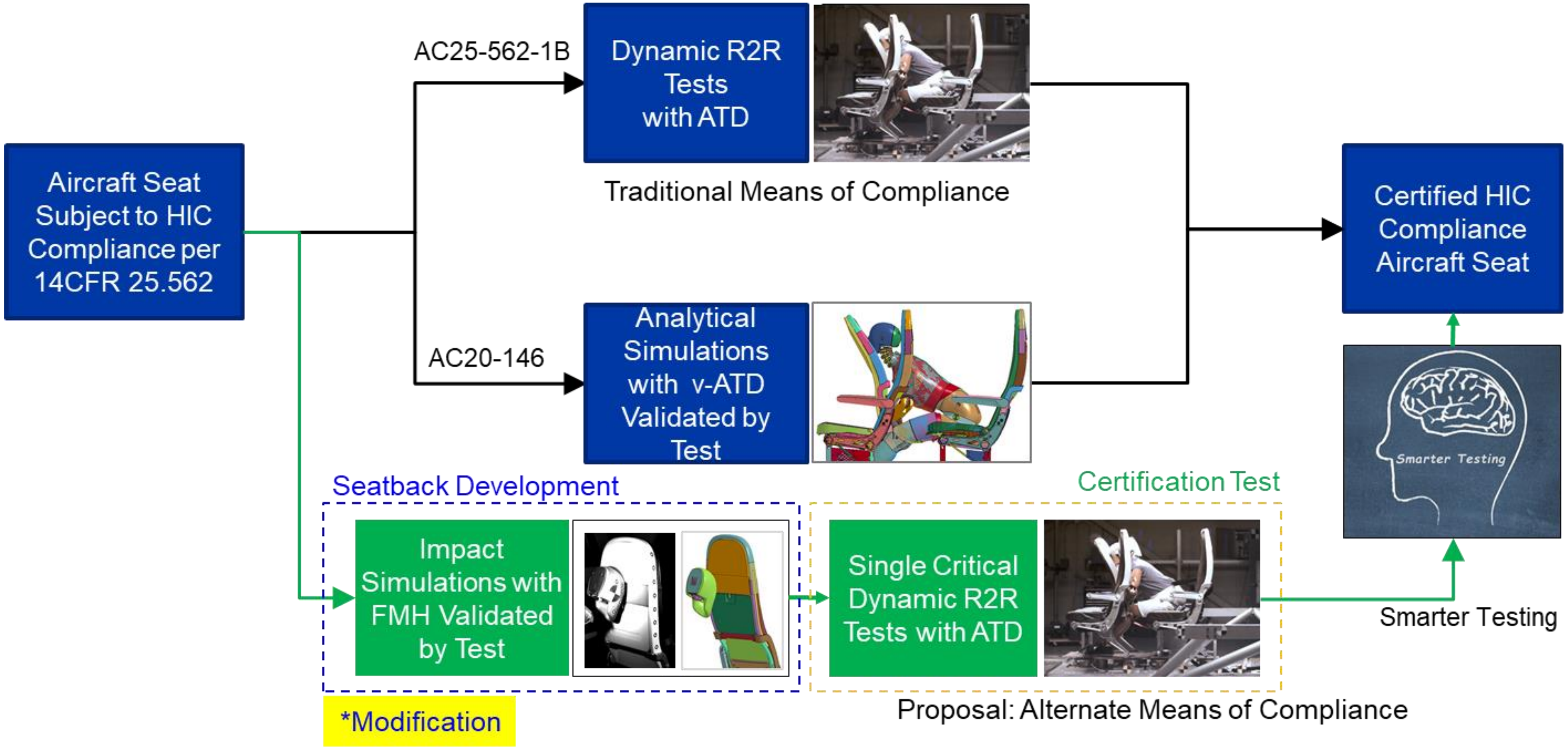
Injury Parameter Prediction Enhancement: Observation

- Passenger safety depends on seat installation environment during emergency landing scenarios
- Each class of seats (E/C, B/C, and F/C) have unique challenge to protect the passengers.
- Airbag and 3-point belt need to have appropriate design features for aerospace application and requirements.



Seat Back Design: Head and Neck Compliance Process

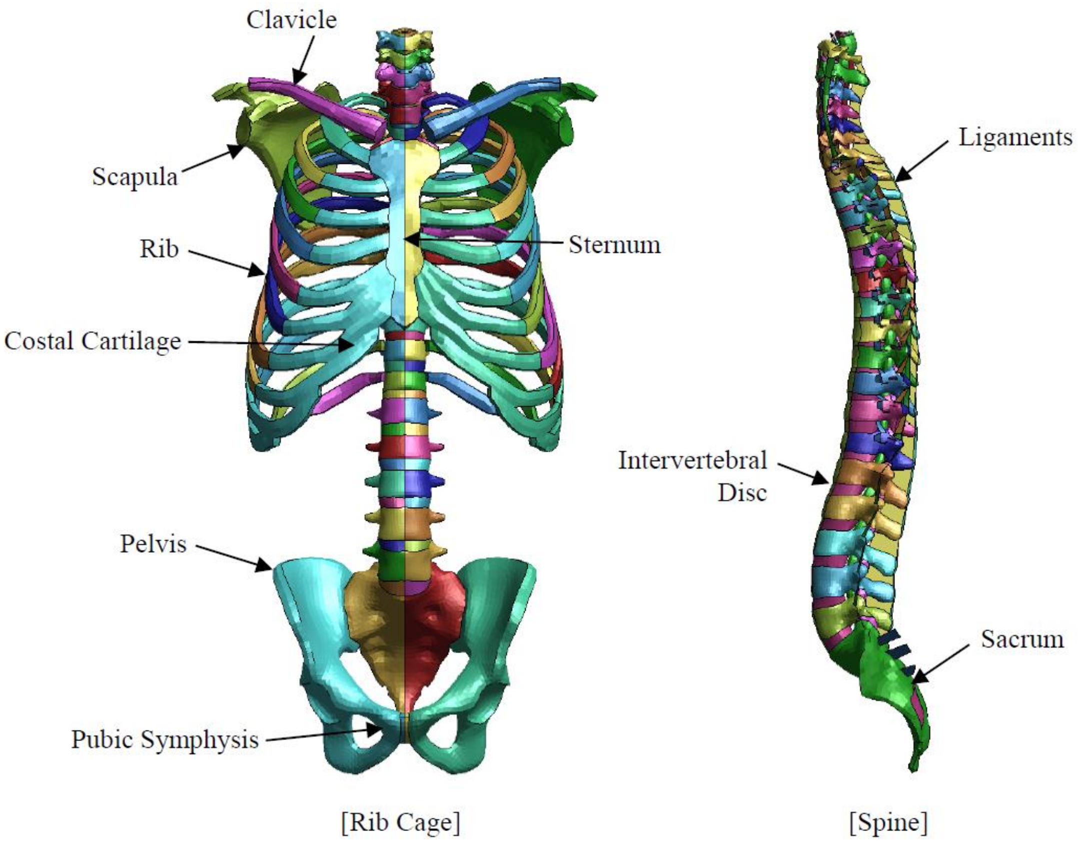
Objective: Use of Headform Model to Obtain Improved HIC (and Nij) prediction in Row-to-Row Seat Test



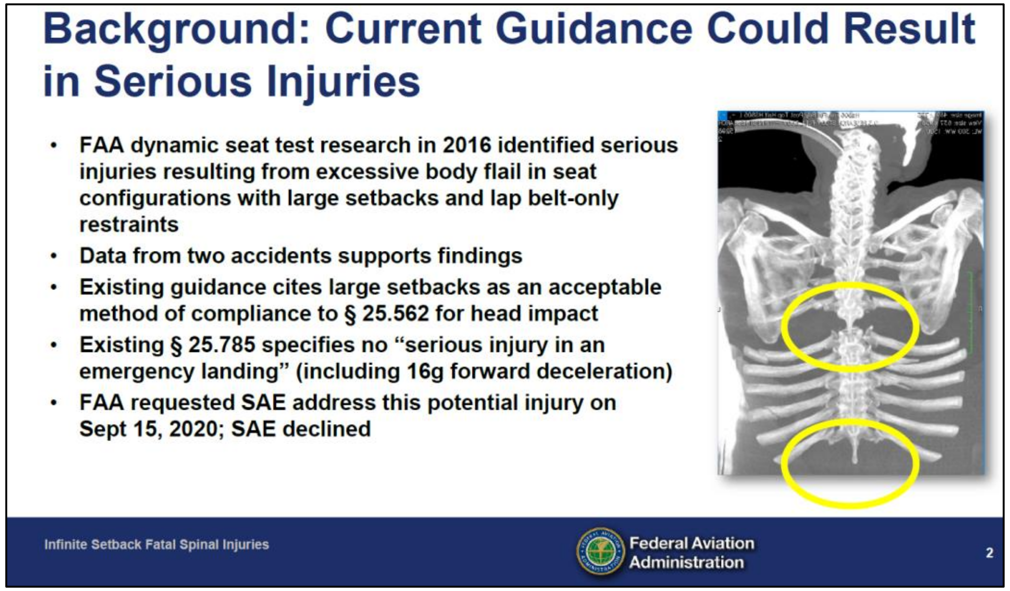
*Note: This process also support seatback modification (monitor change) once seatback is certified by CBA

FAA Concern: Serious Injury in an Emergency Landing

Total Human Model for Safety (THUMS):



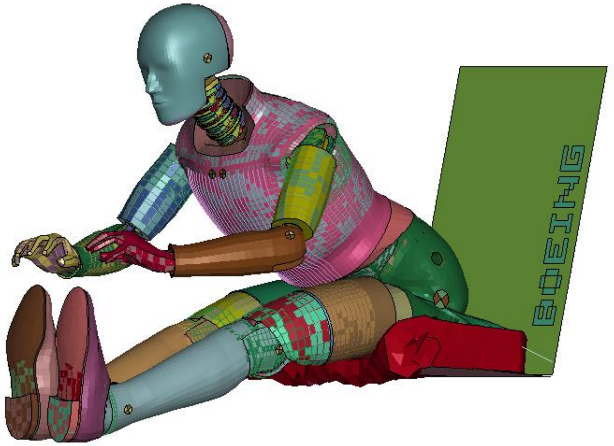
THUMS Skeletal Parts (Torso and Neck Model)

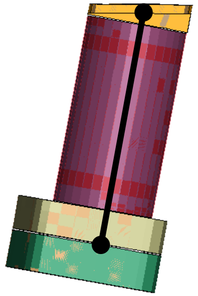


Spinal Tension Load: 16g Forward Load Case

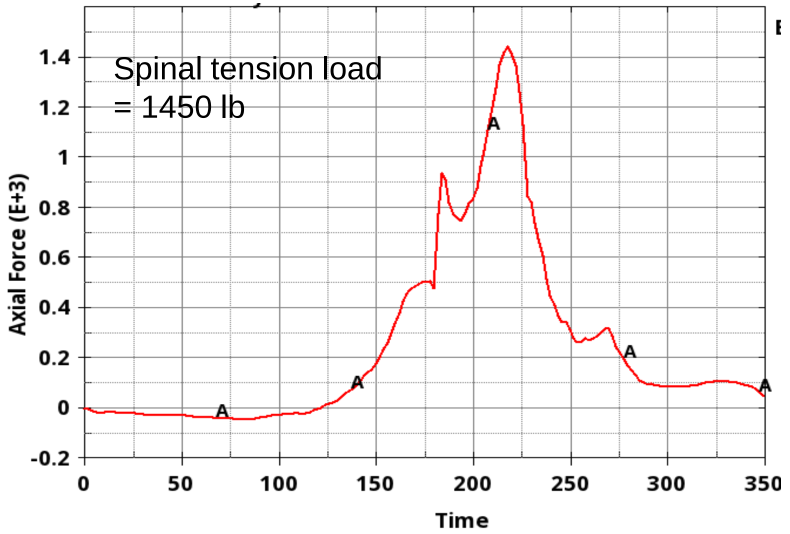
Preliminary ATD responses assessment:

- FAA Hybrid-III v-ATD

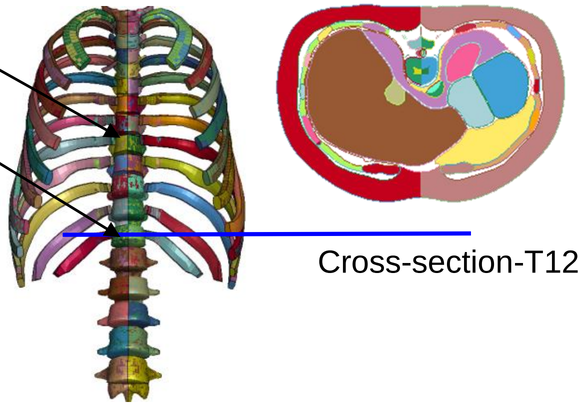


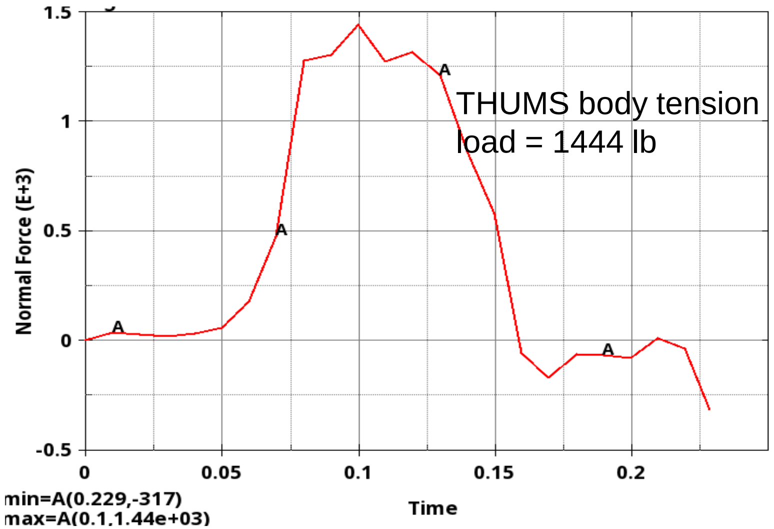


Lower Lumbar Load Cell



- THUMS Model





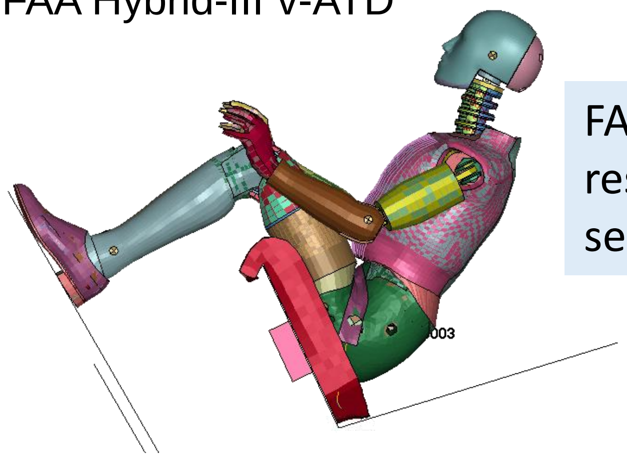
- THUMS T6 and T12 load observed 700 – 900 lb.

Spinal Compression Load: 14g Down Load Case

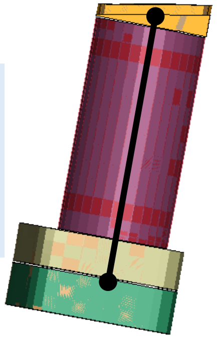
Preliminary ATD responses assessment:

- FAA H-III lumbar load drops quickly as soon as the lumbar column moves from initial position

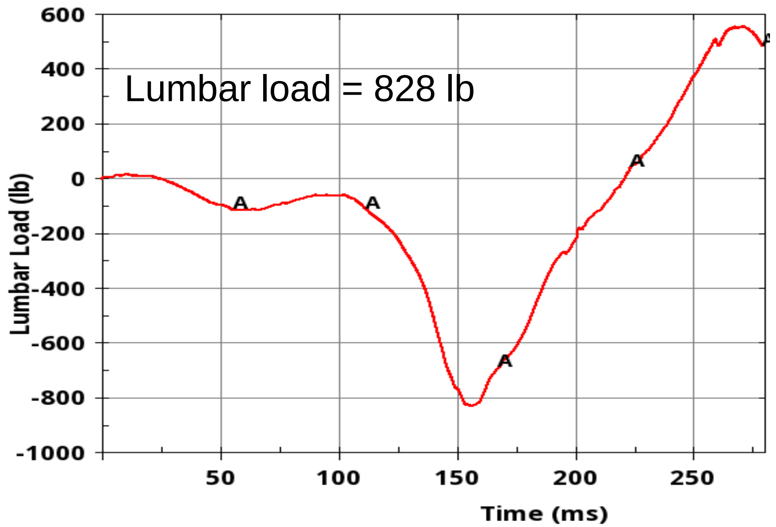
- FAA Hybrid-III v-ATD



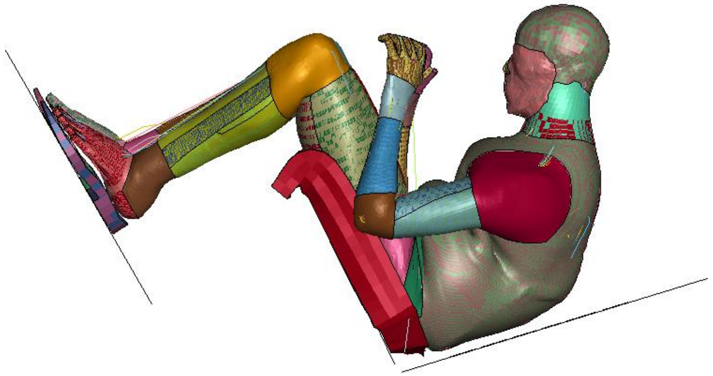
FAA H-III response highly sensitive to angle

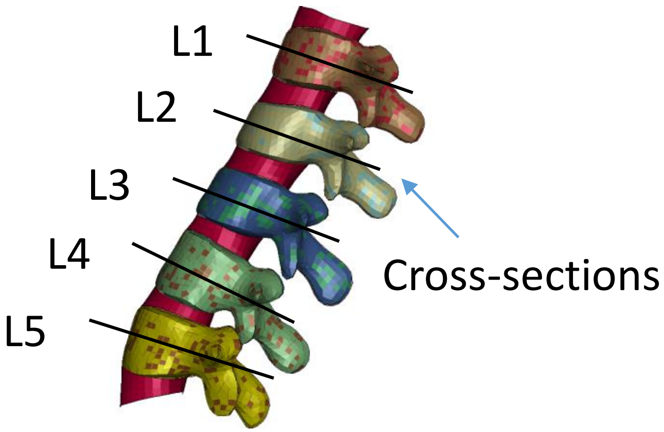


Lower Lumbar Load Cell

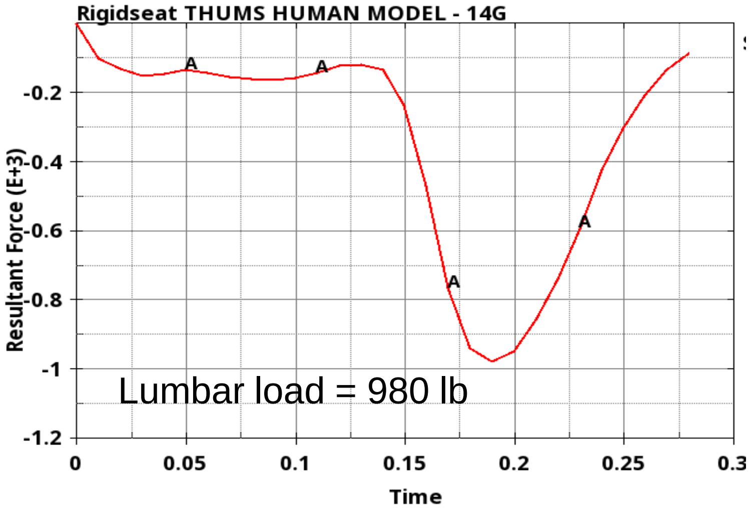


- THUMS Model





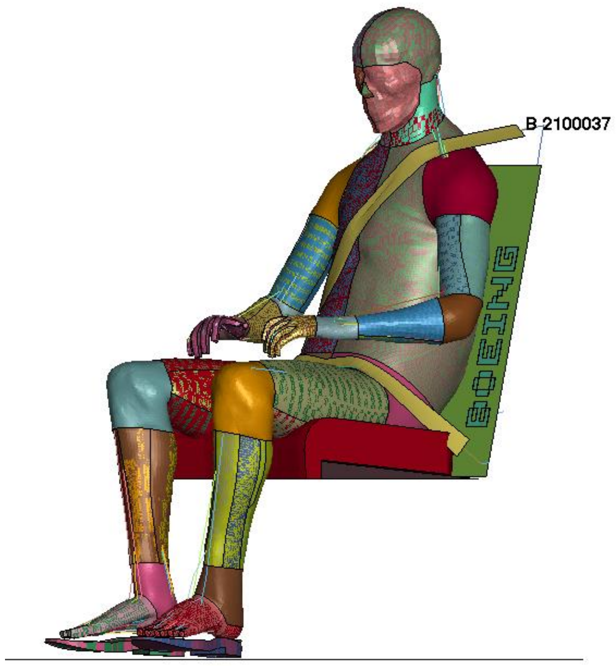
Lower Lumbar L1 – L5

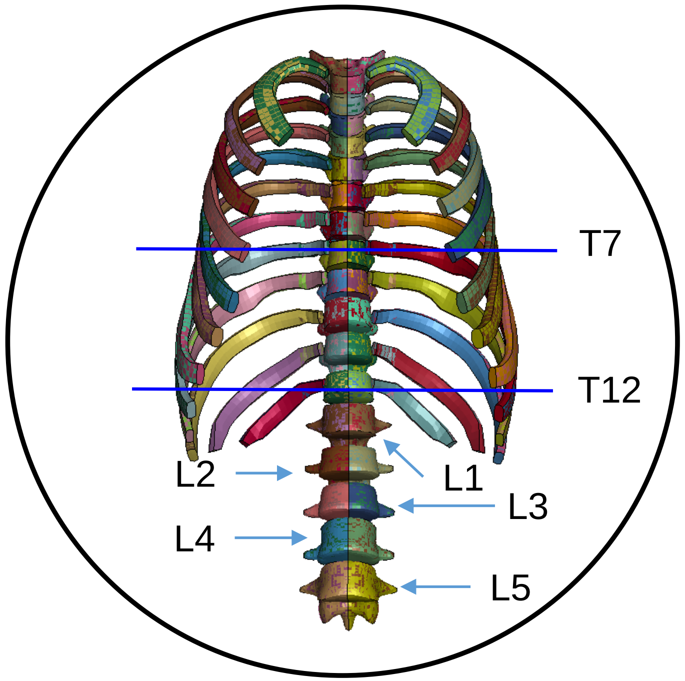


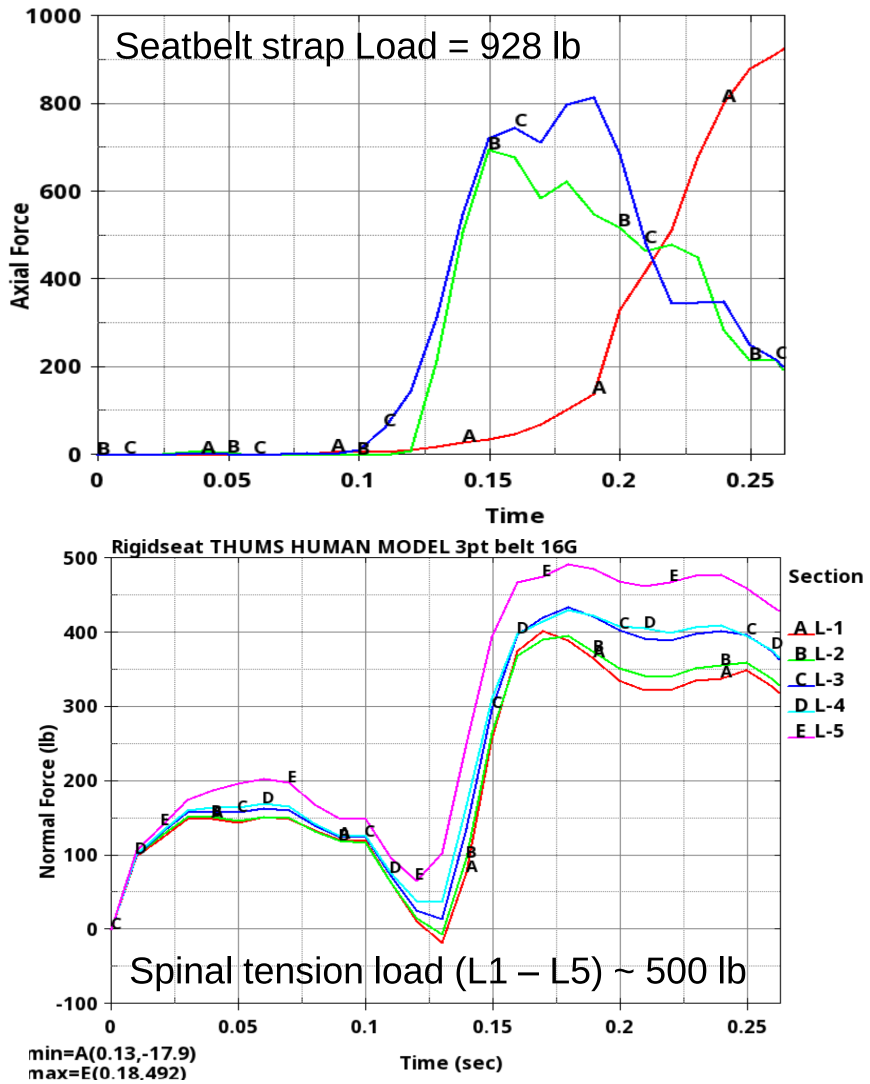
THUMS Model Response: 16g Forward 3-Point Shoulder Belt

Preliminary ATD responses assessment:

- Shoulder Seatbelt strap load
- Spinal tension load
- Neck Injury evaluation



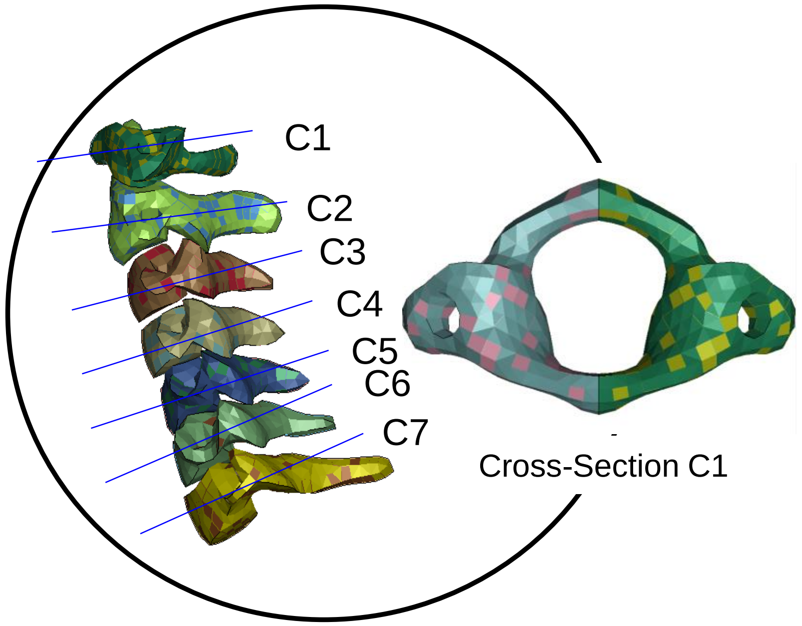




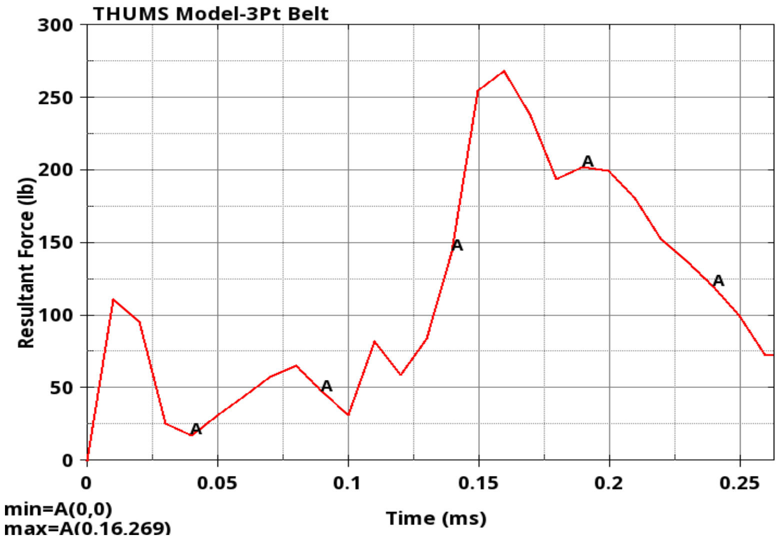
THUMS Model Response: 16g Forward 3-Point Shoulder Belt

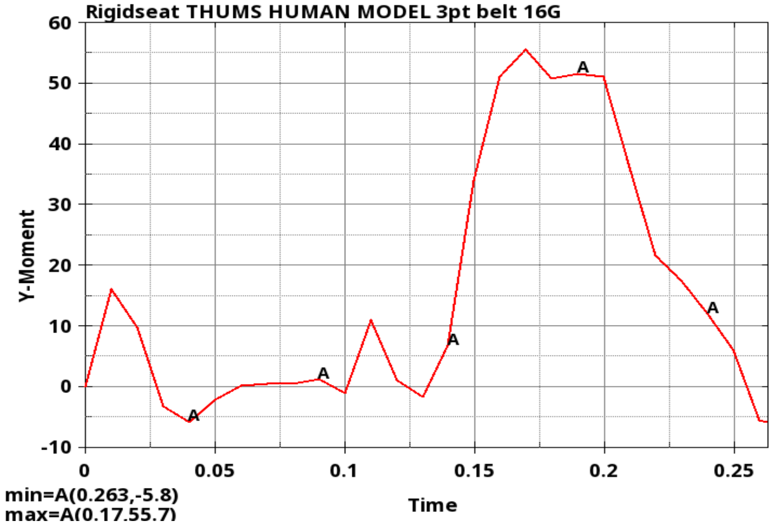
Calculate Nij for Neck Tension and Bending:

- Upper neck C1
- Neck force = 269 lb. and Neck Moment = 55.7 in-lb.
- FAA H-III 50% Neck Injury Criteria Nij = 1.21 > 1.0
    - FAA H-III may over estimate load response in comparison to HBM



Cervical Spine Model C1 – C7

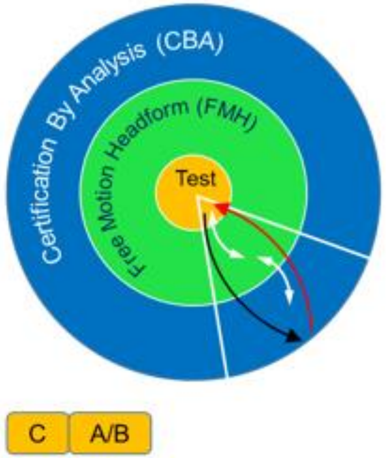




Summary and Next Steps

1. Investigating response of THUMS in comparison to FAA Hybrid-3 ATD – ongoing
   - Current ATD does not accurately represent kinematics/flailing
   - Significant differences in response seen between ATD and THUMS in simulation
2. FMH may be used to assess seatback response and establish level of safety
   - Control initial conditions and impact location
   - Highly repeatable predicting seatback characteristics ensure HIC and Nij prediction
3. Performed simulation studies on front row seating to look at HIC and spinal tension.
   - Airbags and/or 3-point shoulder belt may be needed to mitigate Nij and Lumbar tension, even without contact with bulkhead
4. Review and evaluate FAA proposal for showing and finding compliance for HIC and Nij requirements for airplane seat installation.

Based on FAA proposal on HIC Compliance:



- Perform row-to-row test at center (traditional zone-C) of seatback location using 50% ATD H-II or FAA H-III.
- HIC requirement, HIC < 1000

- Perform FMH Tests to characterized the seatback per requirements including center of seatback
- Validate the R2R using FMH test (initial condition from R2R test)

- Perform FMH simulation to characterize the seatback for CBA considering ATD's, seat pitch, and yaw angle
- Validate the model FMH test and simulation for all impact locations

- For CBA, validate the R2R test using FMH test