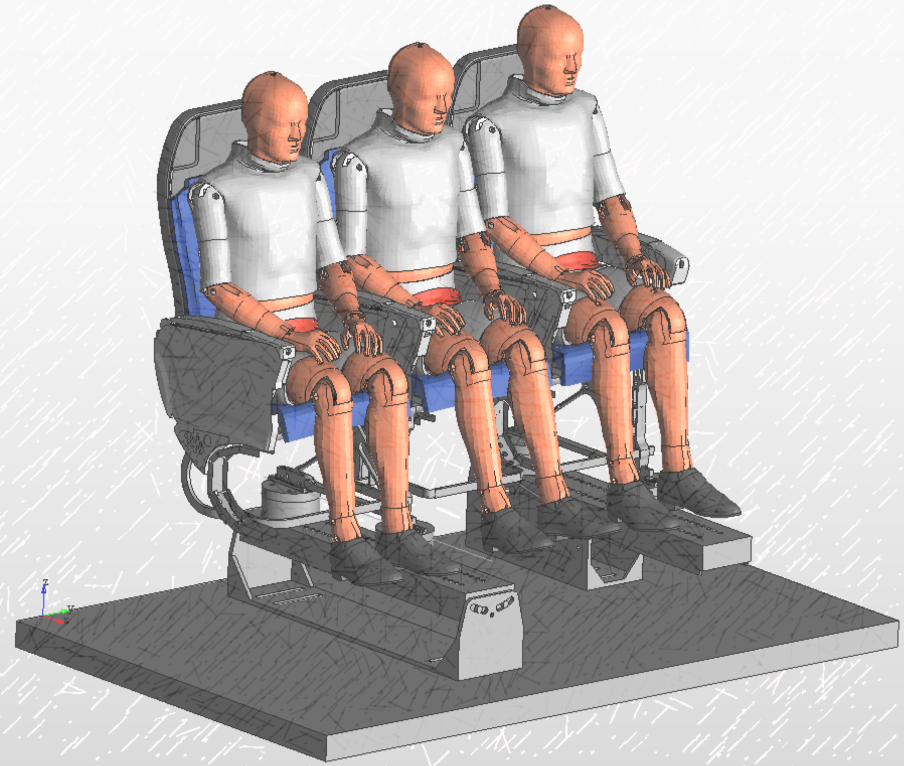

State of the Art Dynamic Seat Simulation

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Olivares, Gerardo
National Institute for Aviation Research (NIAR)

October 27th, 2016

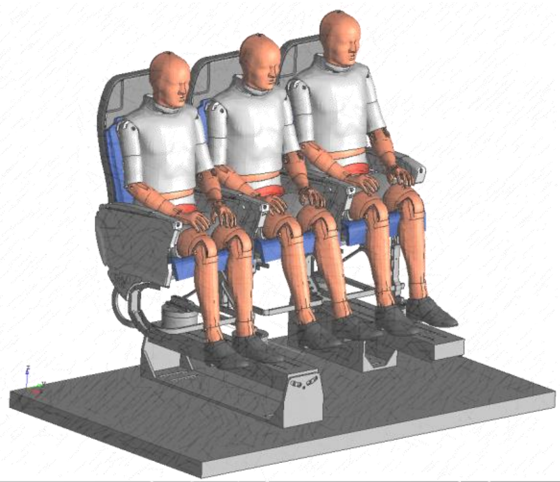
The Eighth Triennial International Fire & Cabin Safety Research Conference

Agenda

- Scope
- NIAR/VIMOTECH Modeling Philosophy
- Seat Finite Element Model Development
- Numerical Analyses Results
  - Pitch & Roll
  - Vertical
  - Head Path
- Numerical Analysis Future

Scope

- Currently, the aerospace industry spends large amounts of resources certifying aircraft seats. The main objective of this presentation is to demonstrate that the current NIAR-VIMOTECH dynamic seat modeling methodology is able to support industry during the certification process by the means of numerical analysis.
- A 3 Place Coach Class Seat is used to perform a blind prediction for the following dynamic testing conditions:
  - Test Condition 1: FAA 25.562 (b)(1) - Pitch - 60 deg. - Roll - 0 deg. - Yaw 0 deg
  - Test Condition 2: FAA 25.562 (b)(2) - Pitch - 10 deg. - Roll - 10 deg. - Yaw 10 deg
  - Test Condition 3: FAA 25.562 - Pitch - 0 deg. - Roll - 0 deg. - Yaw 0 deg
- To show the robustness of the methodology the verification and validation methodology was independently followed by two modelers with different experience (Novice and 2/3 Years of Experience). This will help understanding some of the possible variability within the process.



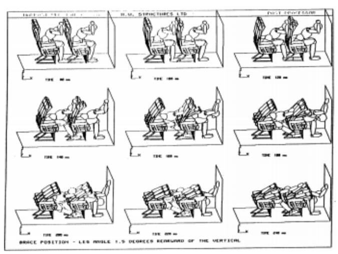
Modeling Philosophy

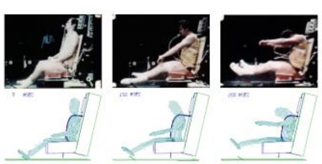
- **Non-Physics Based Modeling:**
  - This approach has been used by the aerospace industry since the introduction of dynamic simulation due to limitations in computing power and computational tools, complexity of the problems, poor understanding of the physics, lack of test-to-test variability data, and poor modeling methodologies.
  - Simulation follows system level testing. Hence models are **not predictable outside of the calibration**.
  - Testing results are used to **calibrate** the model [non-physics based].
  - Models are evaluated by the **calibration-validation methods**.
  - The **validation criteria** is always unreasonable (5 to 10 %) and vague (peak, shape, **subjective**) due to the lack of research and understanding of the real test-to-test variability.
- **Physics Based Modeling:**
  - This approach used by NIAR takes advantage of the advances in computational power, the latest computational tools, years of research to understand the physics, generated test-to-test variability data, and verified & validated (V&V) modelling methodologies.
  - Defined modelling methodologies using the building block approach. Understanding of the physics and testing variability from the coupon to the system level. Taking a **conservative modeling approach** based on data derived from R&D and the Building Block Approach to define simplified models when required. The definition of the numerical model is not driven by system level test results, is driven by a predefined building block modeling methodology. **NO CALIBRATION required.**
  - Simulation **predicts** system level test results within the scope and scatter of the physical test results.
  - **Objective validation** criteria based on an understanding of the test-to-test variability. Defined objective validation metrics (i.e. Sprague and Gears). The correlation level between simulation and testing is driven by an understanding of the test-to-test variability.

NIAR

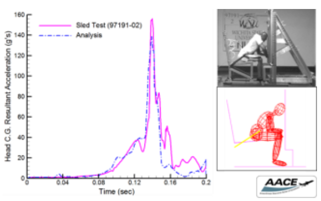
Evolution of Dynamic Seat Simulation in the US

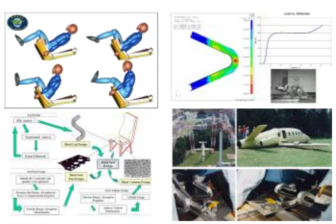
1975 – 1997 FAA Sponsors the Development of SOMLA and SOMTA. Air Force sponsors CVS [70's] and ATB [80's]





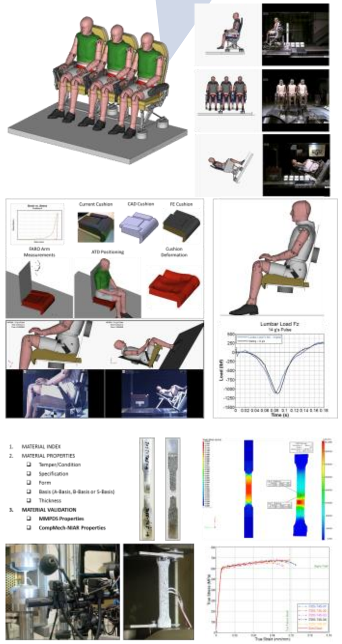
1990 – 2004
NIAR,FAA[CAMI],NASA,INDUSTRY,TNO , AGATE and ADMARC R&D Projects





2005-Present

NIAR-FAA (JAMS CBA R&D Projects), NASA, Industry



Further Reading:

- Soltis S. , "Overview of Usage of Crash Dynamic Analytical Methods in Civil Aircraft Research and Certification Programs " , FAA Cabin Safety Conference, 2007.
- Olivares, G., Lankarani, H., Nagarajan H., "A Virtual Multibody and Finite Element Analysis Environment in the Field of Aerospace Crashworthiness", Chapter in the book, Virtual Nonlinear Multibody Systems, Schiehlen and Valasek (Eds.), NATO Science Series, II, Vol. 103, pp. 187-212, ISBN 1-4020-1339-6, Kluwer Academic Publishers, 2003.

What are we trying to solve?

The finite element approach is based on replacing a continuum with discrete elements. Different element types are available (1D, 2D, and 3D) and they are derived based on assumed displacement fields or extrapolation algorithms (constant or linear strain, regular or iso-parametric, …etc.). Furthermore, such elements are derived while addressing the requirements of equilibrium and compatibility and an assumed material model. Generally the transformation from the continuum to the finite element model will result in the following equation of equilibrium:

$$[\boldsymbol{m}] \cdot \{\ddot{x}\} + [\boldsymbol{c}] \cdot \{\dot{x}\} + [\boldsymbol{k}] \cdot \{x\} = \{\boldsymbol{F}(\boldsymbol{t})\}$$

- $\{\boldsymbol{F}(\boldsymbol{t})\} =$ ***is the vector describing the force time histories applied to specific nodes in the system***
- $\{\ddot{x}\}, \{\dot{x}\}, \{x\}$ **= represent the nodal accelerations, velocities and displacement of the structure at any time t**
- **[m] = is the mass matrix**
- **[c] = is the damping matrix**
- **[k] = is the stiffness matrix**

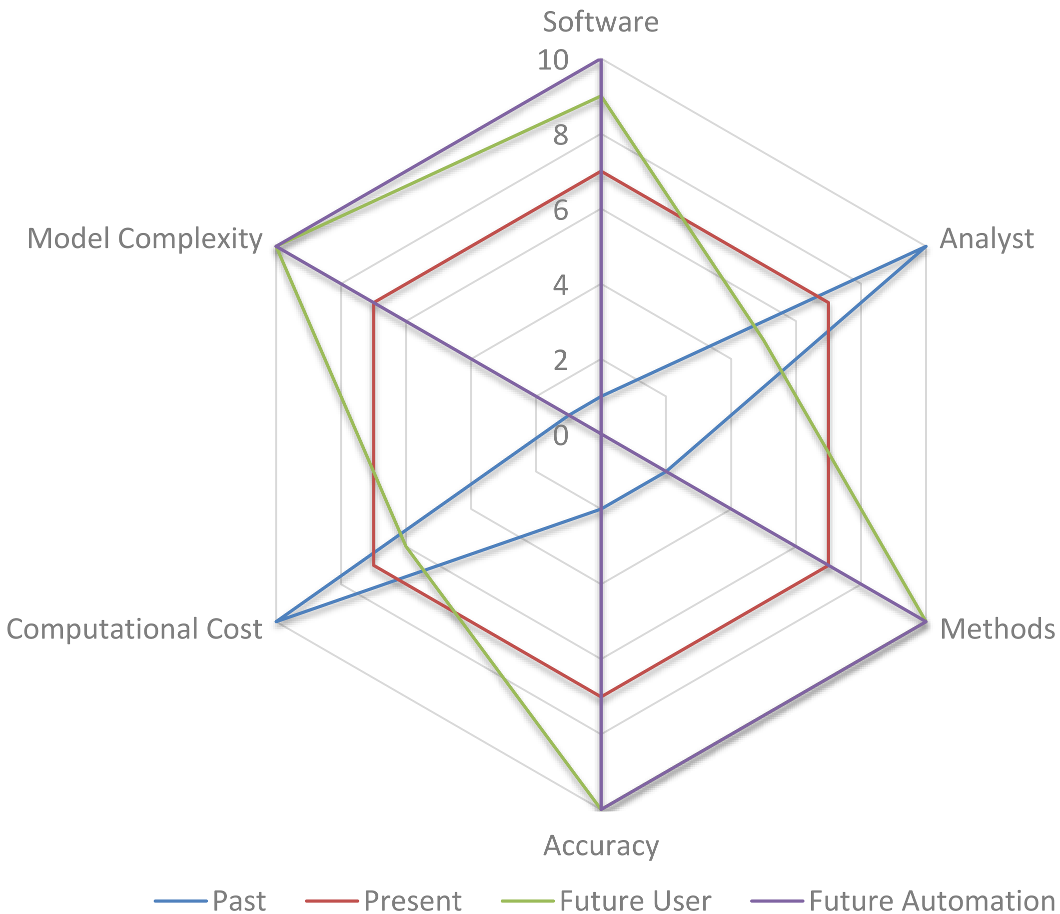
These parameters are a function of the MASS, GEOMETRY, and MATERIALS (Properties and Formulations) that define the structure being analyzed.
If anyone conducts a structural analysis with the wrong mass, and/or the wrong geometry, and/or the wrong materials they are just wasting their time and valuable resources creating pretty colorful pictures.

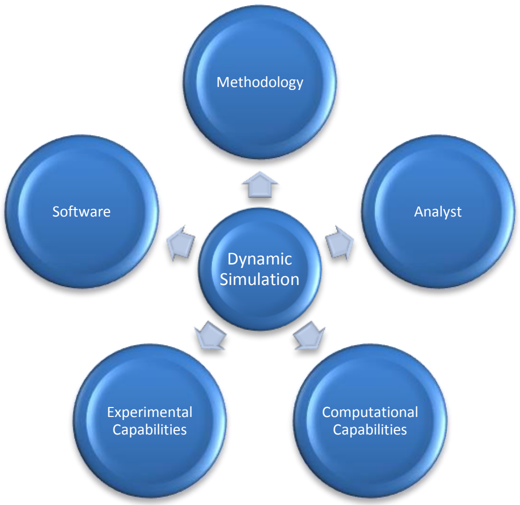
What are the major reasons for not having predictable seat models?

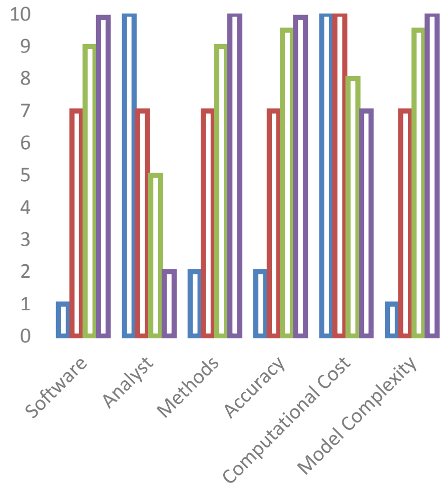
- Most companies have no verified and validated processes in place and rely on the experience of the analyst.
- Too little focus and scrutiny to the MASS, GEOMETRY, DISCRETIZATION, BASIC MATERIAL DEFINITIONS , and MODELLING PROCEDURES **[70 to 85 % of the solution]**
- Too much focus and scrutiny on advanced material models, strain rates effects, damage models ……….. **[15% to 30 % of the solution]**
  - **FACTS for Coach Class Seats:**
    - **70 % of the structure elastic behavior**
    - **Strain Rates on the remaining 30 % of the structure bellow 7/s**
- **Designs with a margin of safety of 0.00000001** [a fair comparison would be with multiple test results]

$$[\boldsymbol{m}] \cdot \{\ddot{x}\} + [\boldsymbol{c}] \cdot \{\dot{x}\} + [\boldsymbol{k}] \cdot \{x\} = \{\boldsymbol{F}(\boldsymbol{t})\}$$

Evolution Dynamic Simulation





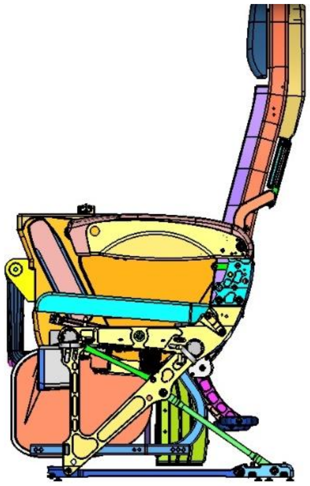


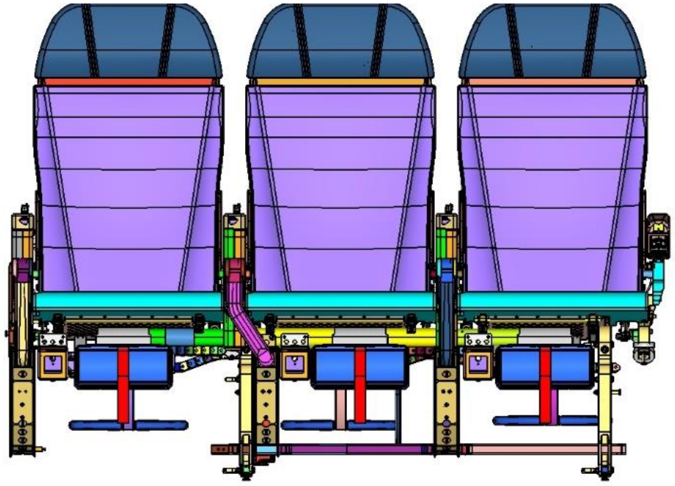
Certification by Analysis

Seat FE Model Development

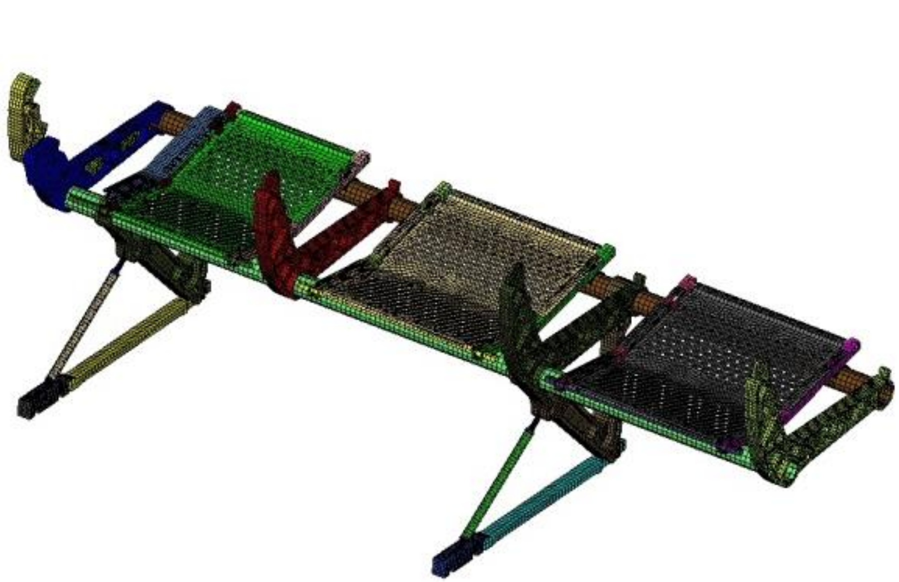
Seat CAD Overview

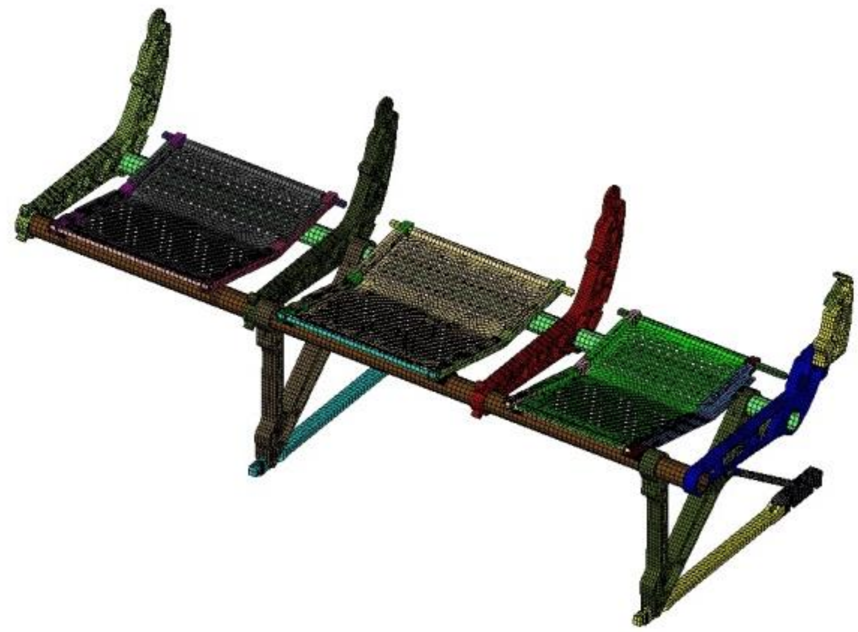
- Seat Overview
  - Economy Class 3 Place Seat
  - 2-pt. Belt System
  - Weight: 205 lbs



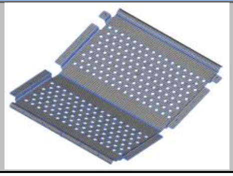


Primary Load Path Mesh





Mesh Quality Documentation

No	PIC	Component Name	Part ID	No. of Parts
1		857794-001	5000001	1

Quality Documentation

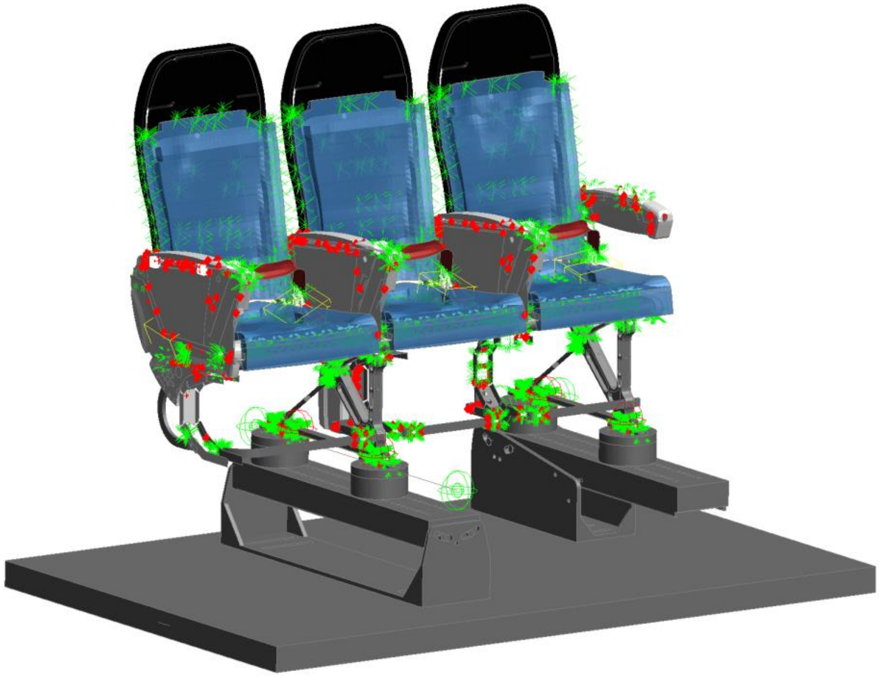
Part Total Elements	Minimum Length	Maximum Length	Aspect Ratio	Warpage	Jacobian	Maximum Quad Angle	Minimum Quad Angle	Maximum Triangle	Minimum Triangle
10210	1.9	4.19	6	8.1	0.7	132	53	110.6	26

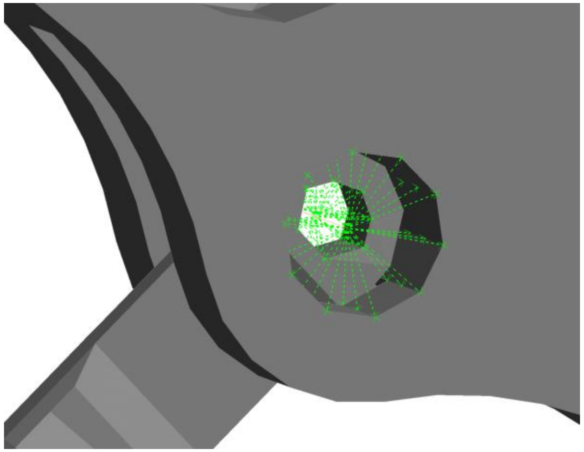
Element Checks

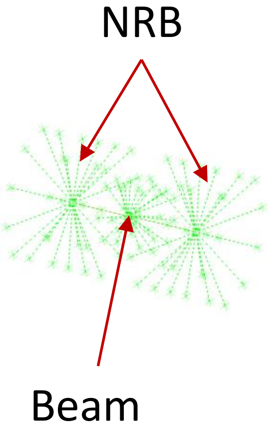
Checks	Status (Yes/No)
Quality Criteria	YES
Normal	YES
Duplicates	YES
Connectivity	YES
Free Edges	YES

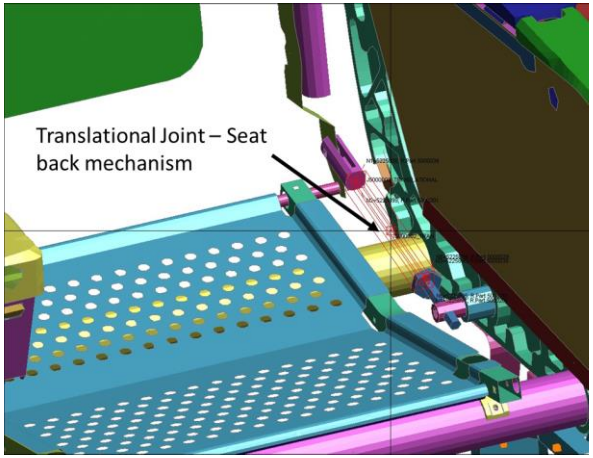
Seat Connections Definition

- 146 NRB – Beam: Bolts
- 6 Joints
  - 4 Translational
  - 2 Spherical
- Rigid Beams (Spot-welds)

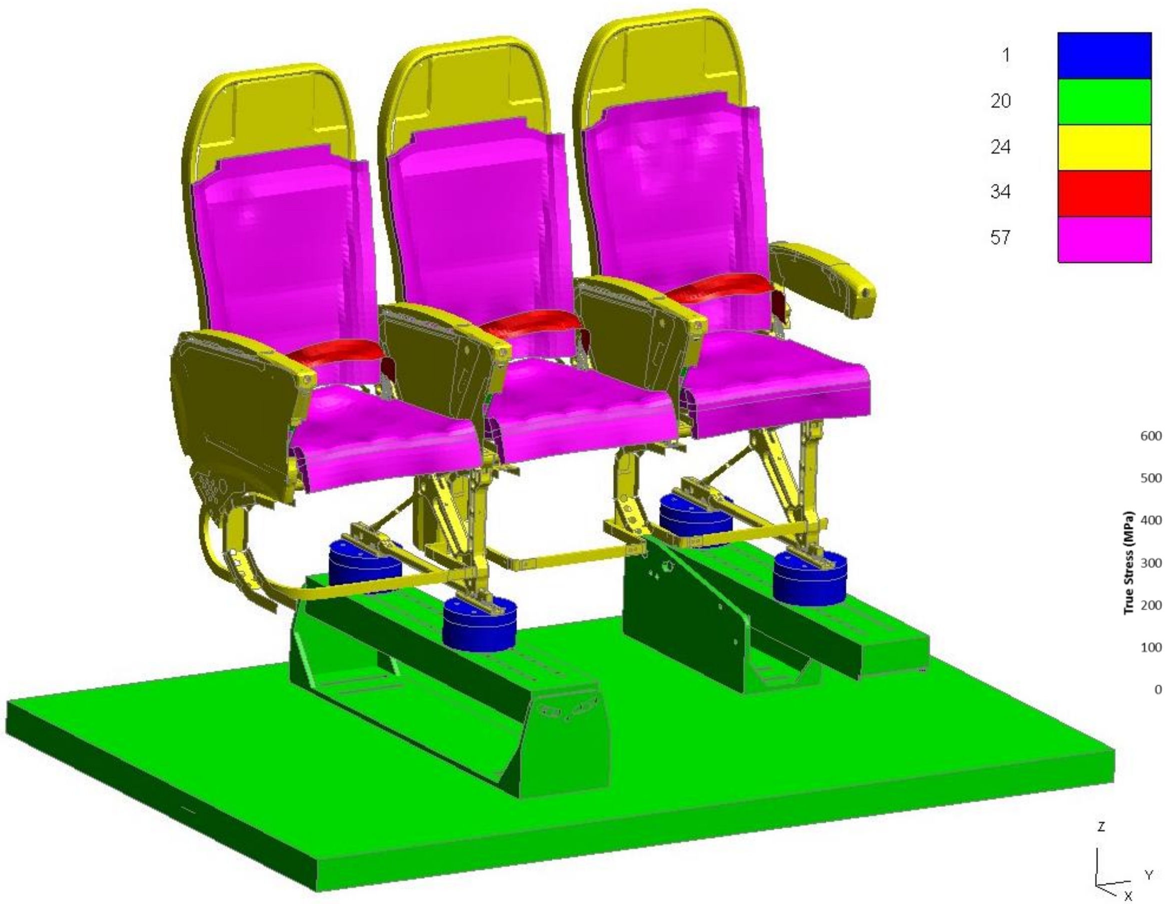






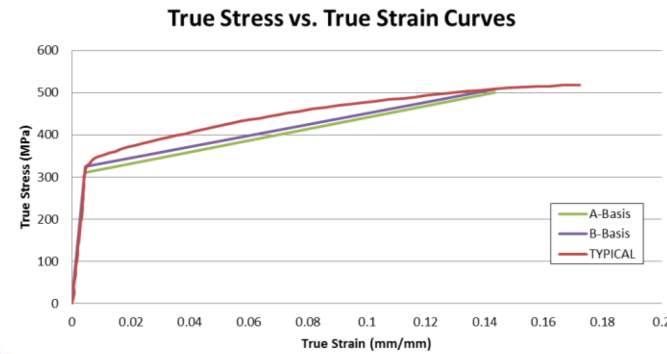


Material Definitions



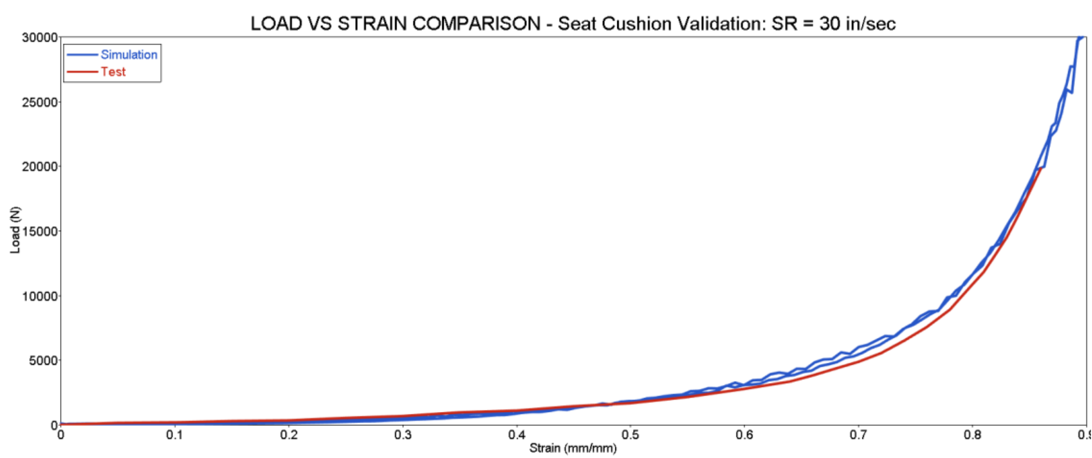
MATERIAL TYPE

1		1: MAT_ELASTIC
20		20: MAT_RIGID
24		24: MAT_PIECEWISE_LINEAR_PLASTICITY
34		34: MAT_FABRIC
57		57_MAT_LOW_DENSITY_FOAM

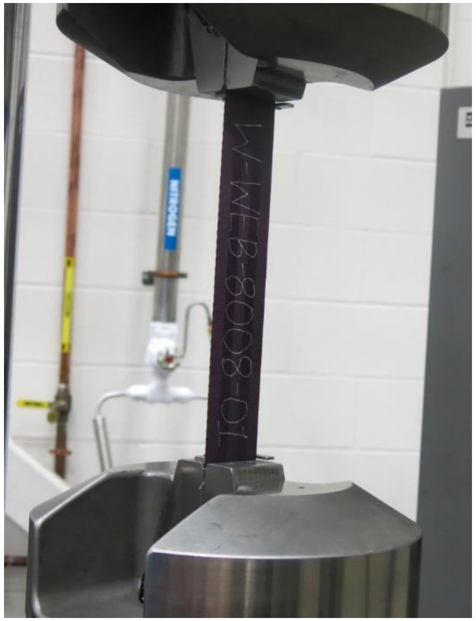


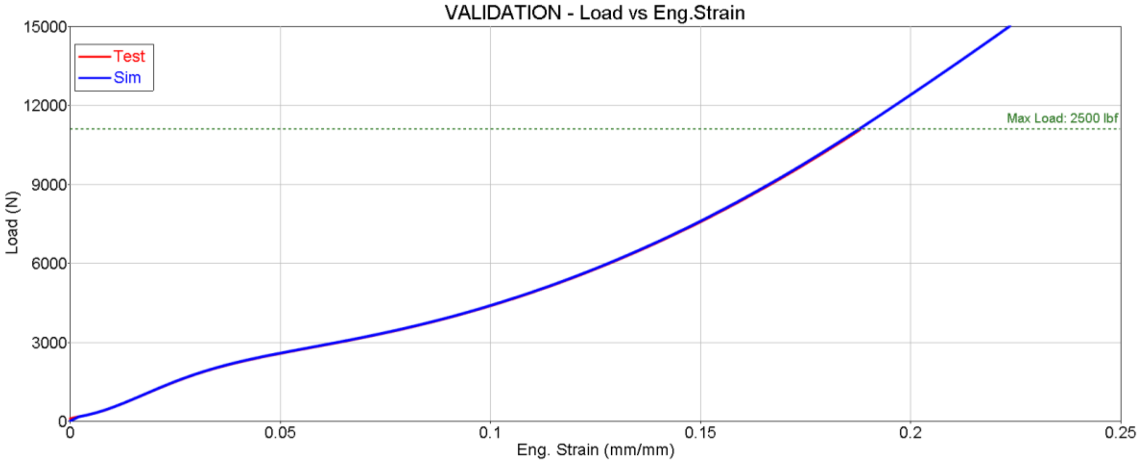
Cushion Characterization – Test Setup

- Component Level Test
  - Dynamic
  - Quasi-static



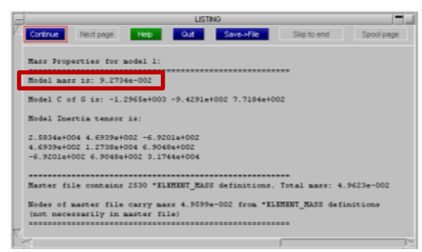
Seat Belt Characterization – Test Setup





Seat Weight Check

Assembly/Component	Weight (lbs)
Seat without IFEs	133
Video Monitor	18
Literature	15
Life Vest	6
Armrest	12
Video Arm	15
Electric Equipment	6
Total	205



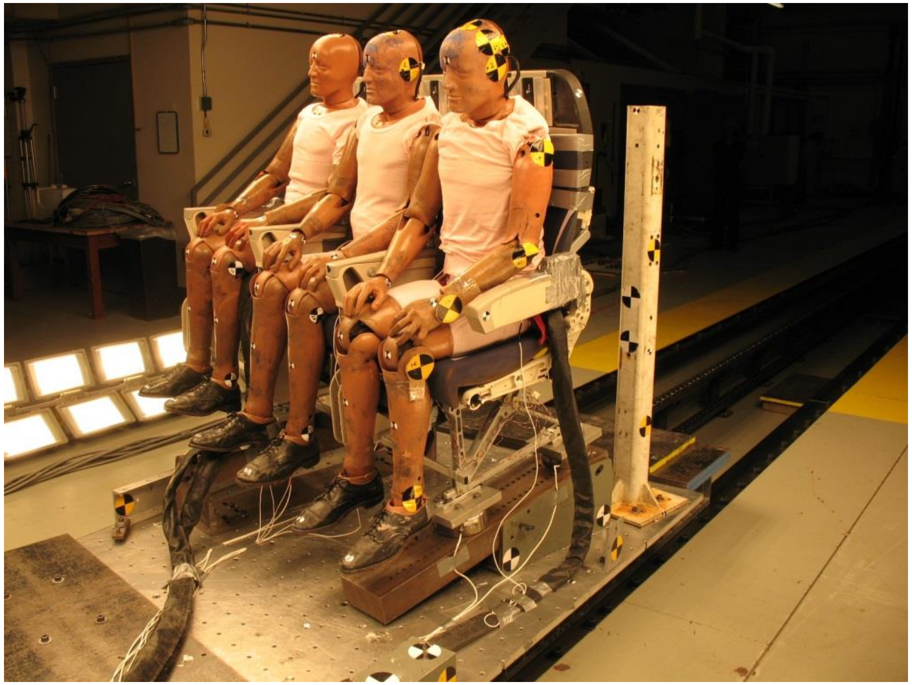
Seat Model Weight
= 92.7 kg
= 204.4 lbs

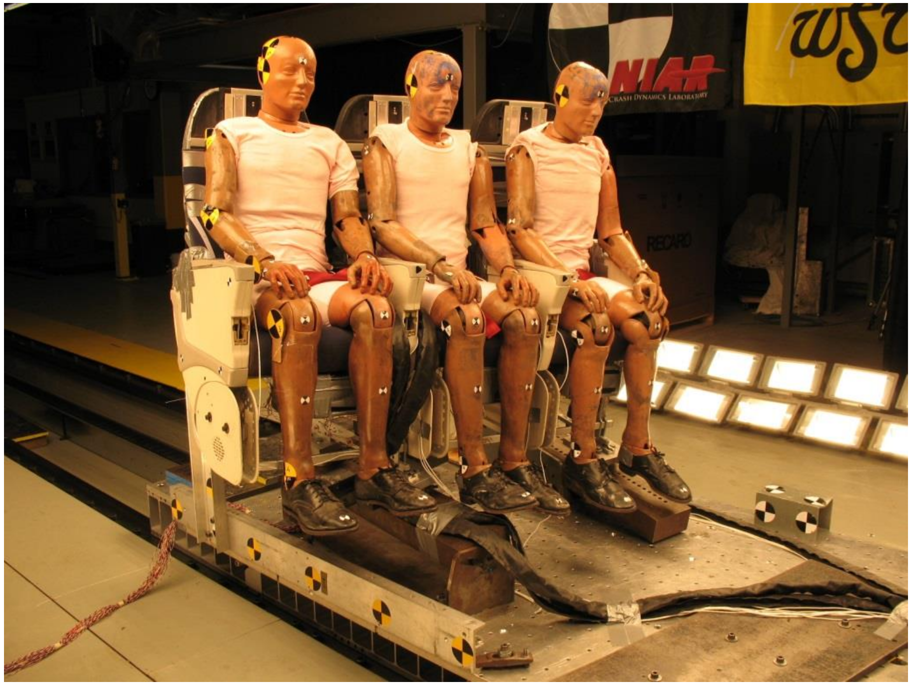
Certification by Analysis

Numerical Analysis
Pitch & Roll Configuration

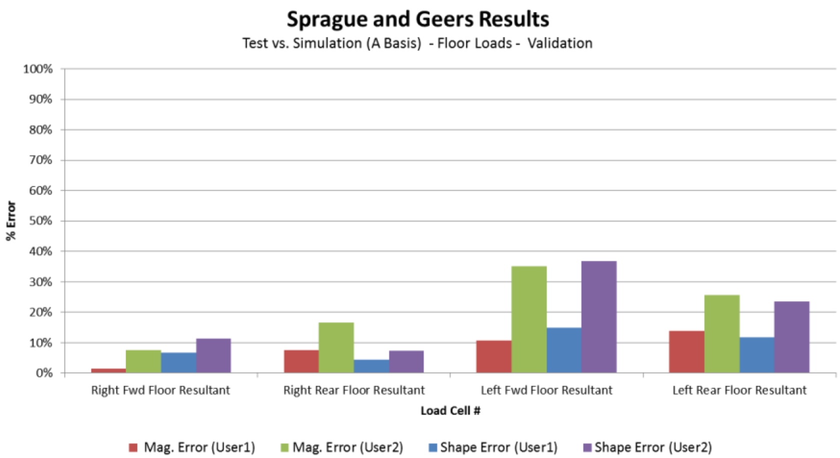
Pitch & Roll Test (08102 – 4)

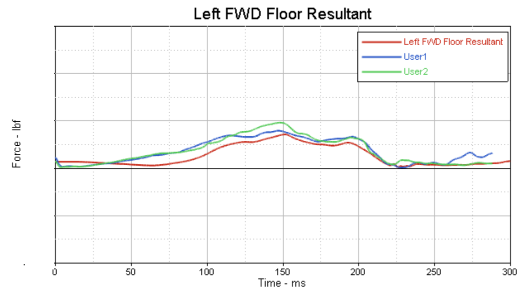
- Test Condition
  - Three Passengers Economy Aircraft Seat
  - Standard 2-pt Belt
  - FAA 25.562 - Pitch - 10 deg. Down - Roll - 10 deg. CW - Yaw 10 deg. CW

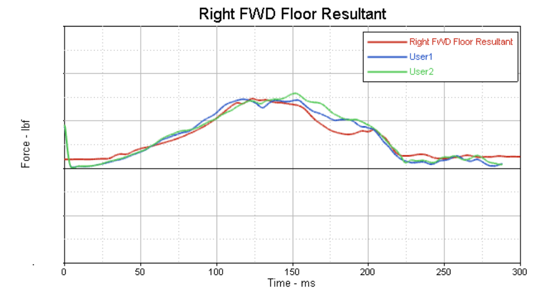


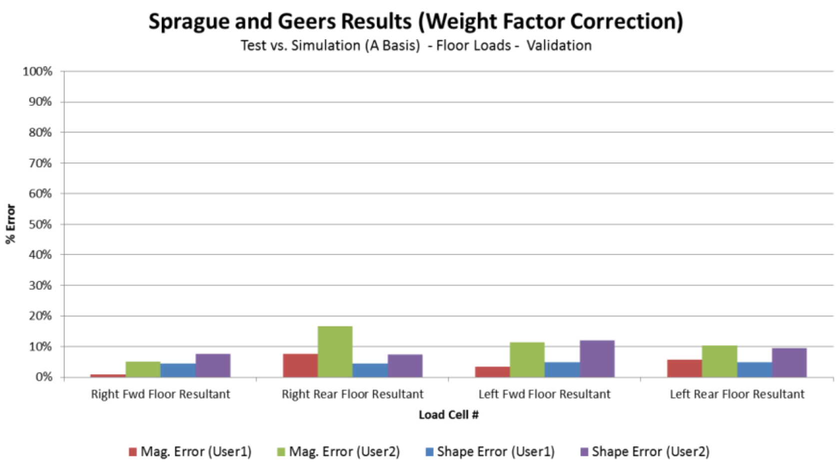


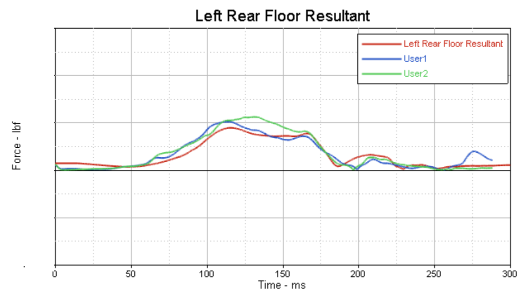
Floor Loads – Sprague and Geers

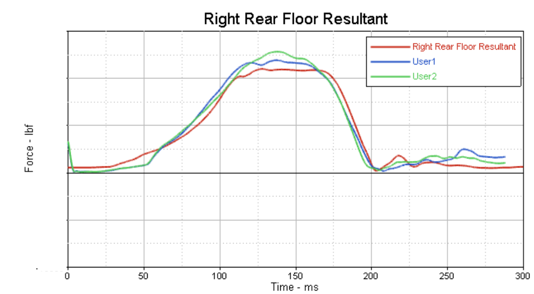




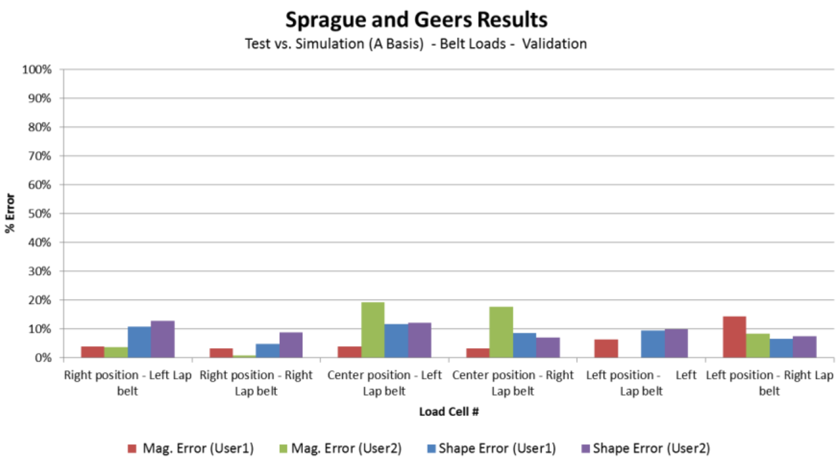


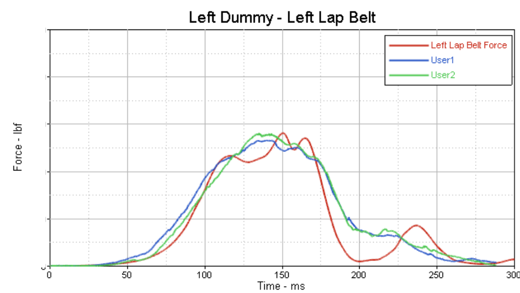


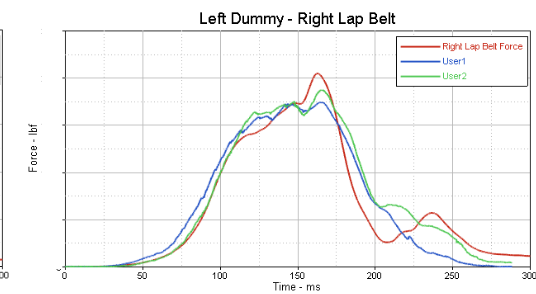


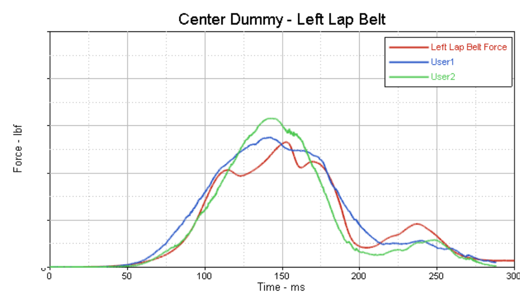


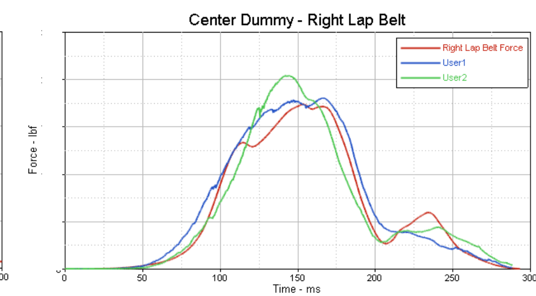
Belt Loads – Sprague and Geers

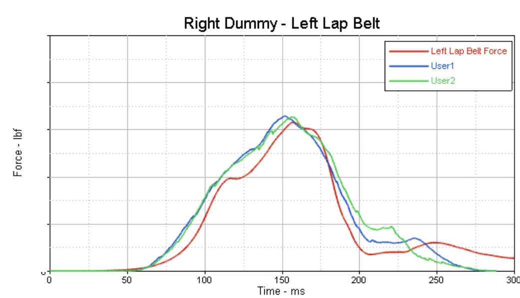


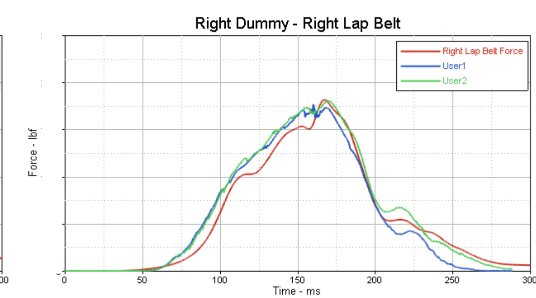




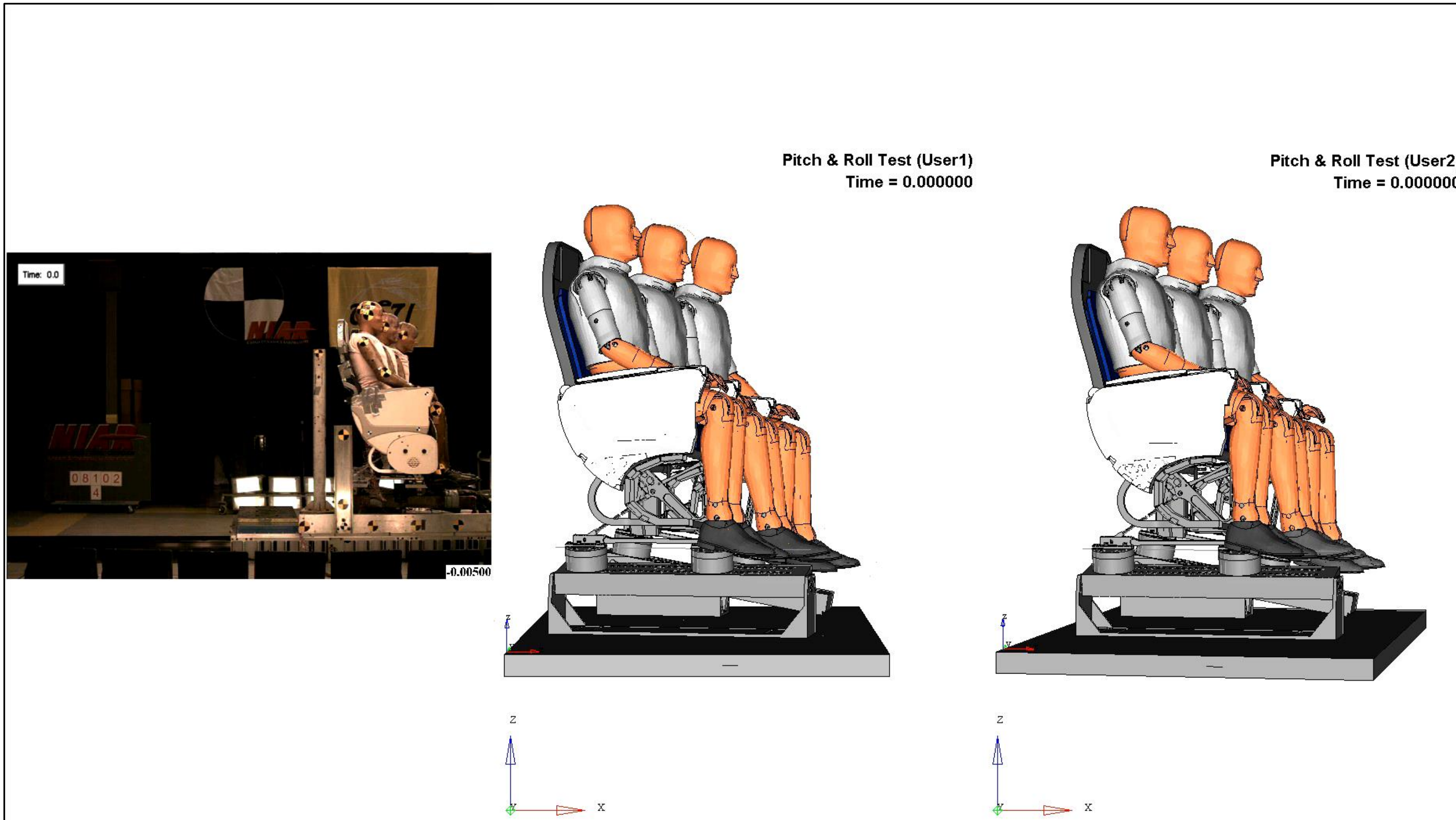








Pitch & Roll – Kinematics Comparison

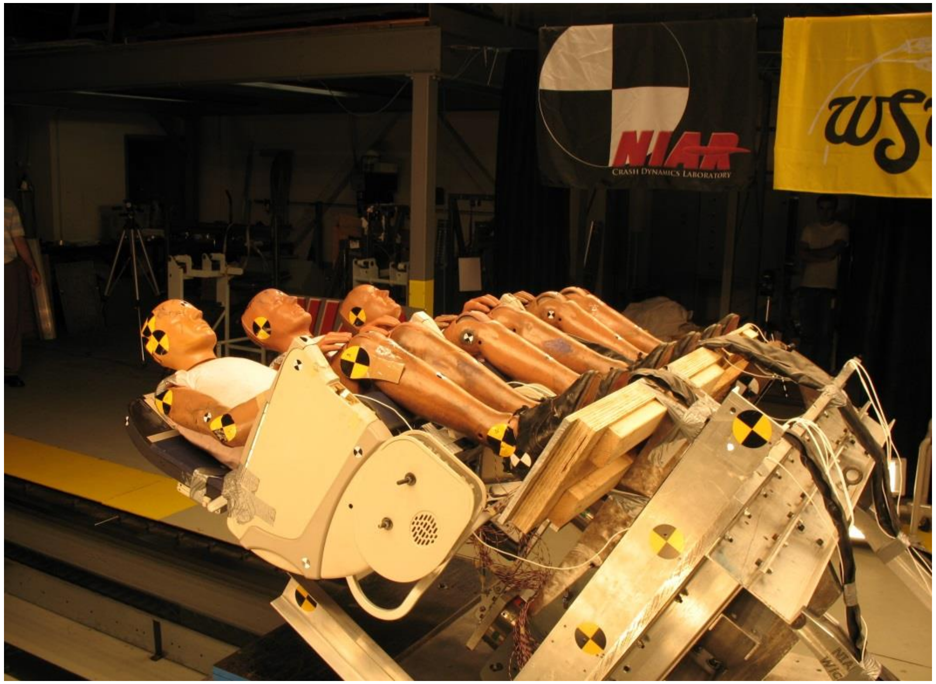


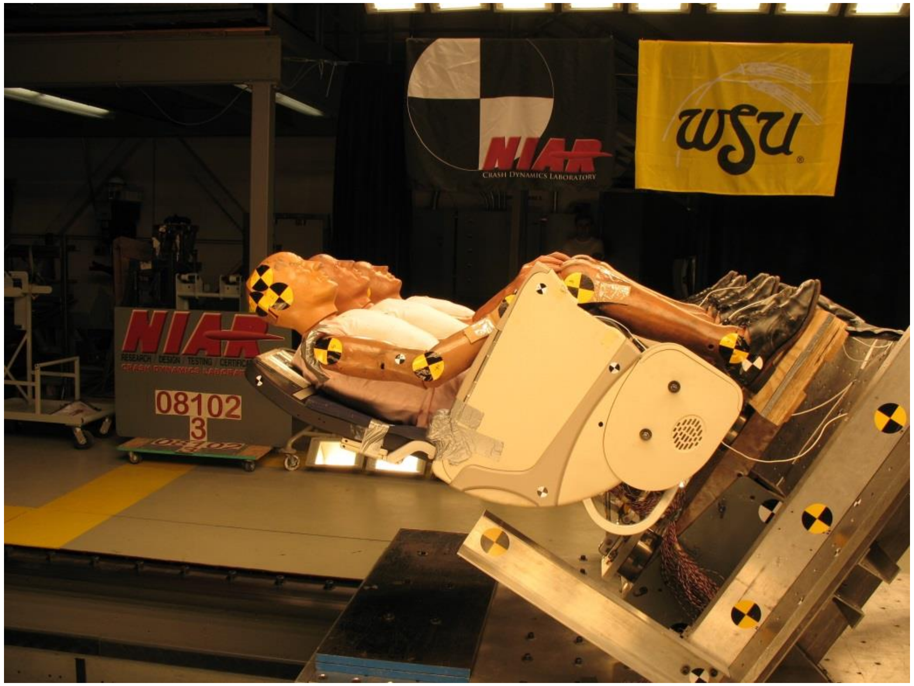
Certification by Analysis

Numerical Analysis Vertical Configuration

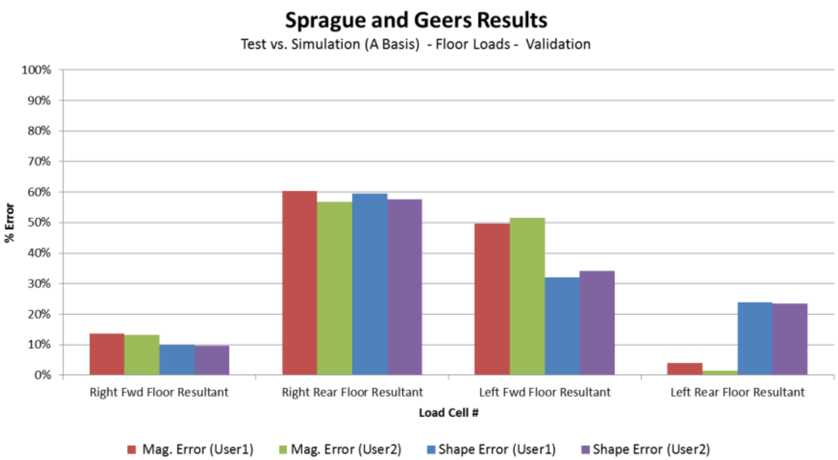
Vertical Test (08102 – 3)

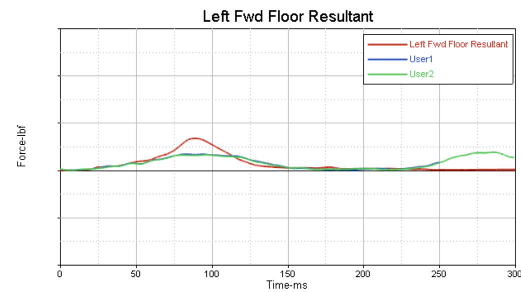
- Test Condition
  - Three Passengers Economy Aircraft Seat
  - Standard 2-pt Belt
  - FAA 25.562 - Pitch - 60 deg. Up

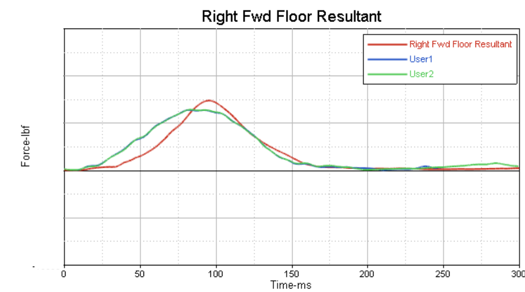


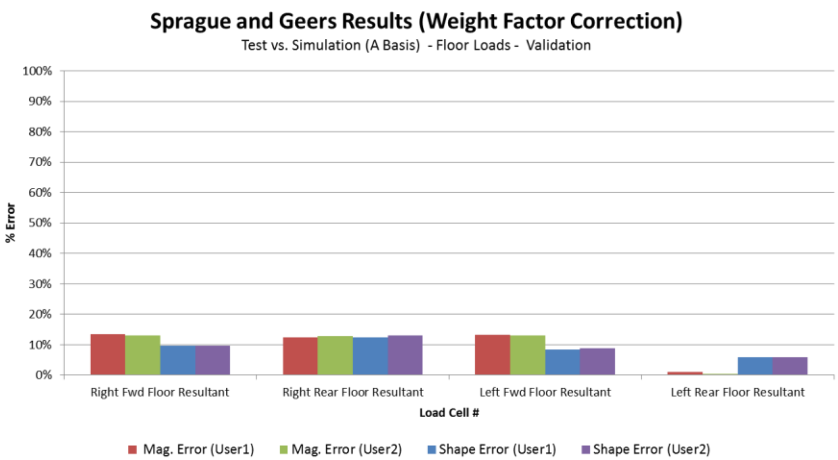


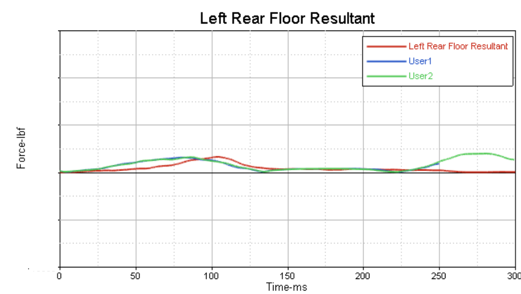
Floor Loads – Sprague and Geers

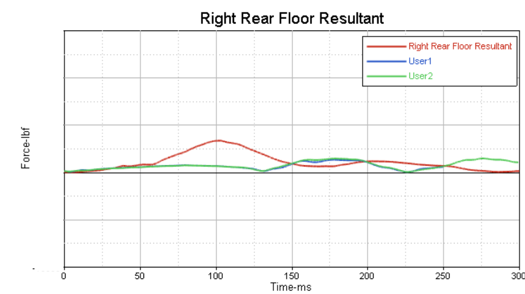




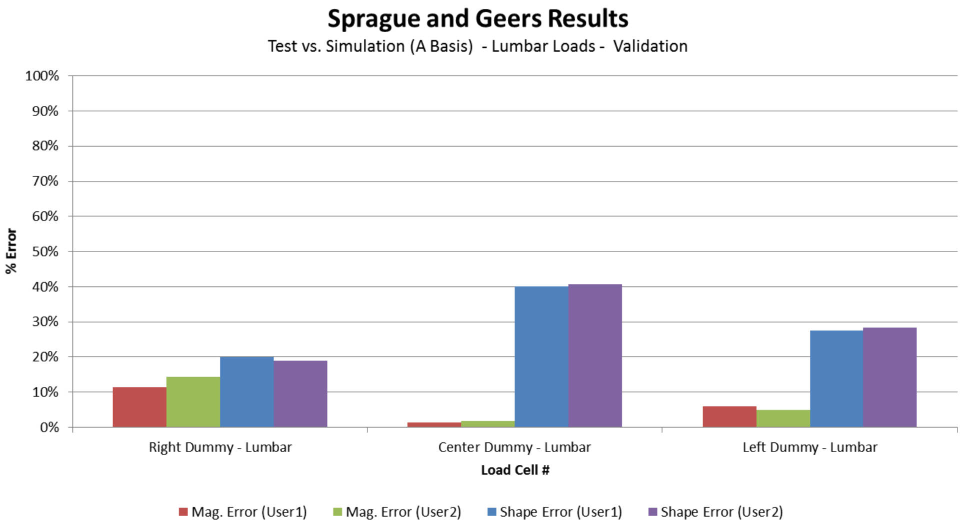


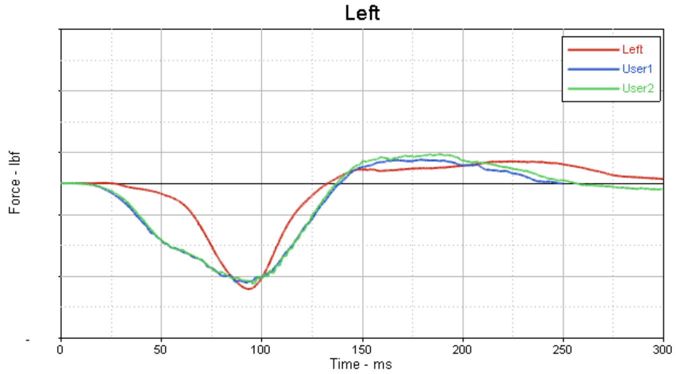


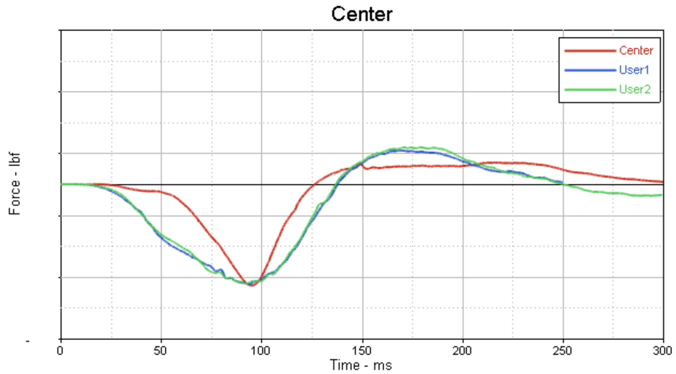


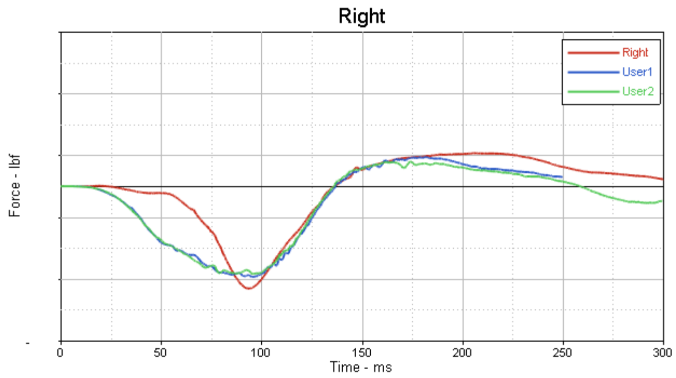


Lumbar Loads – Sprague and Geers

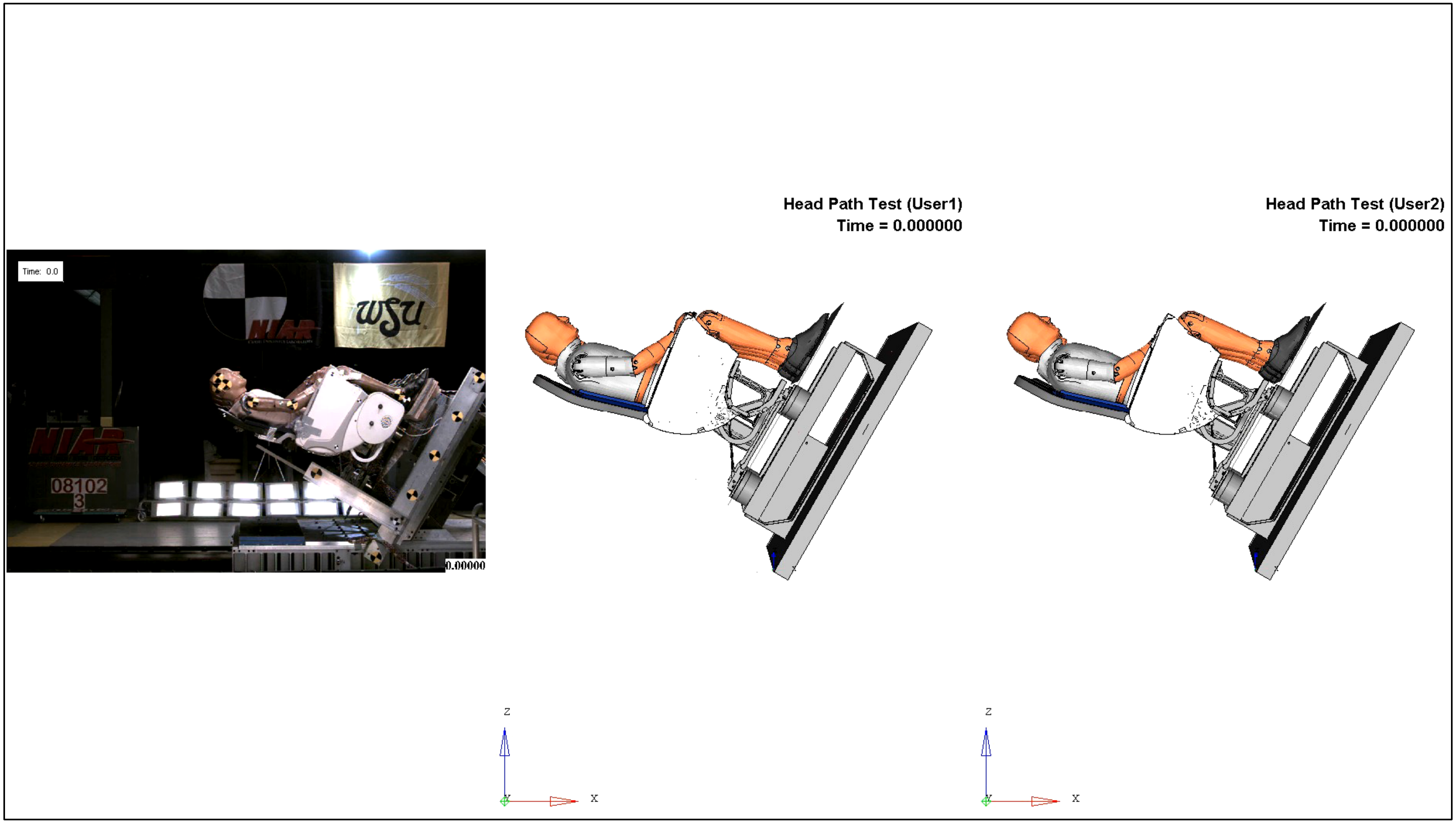








Vertical – Kinematics Comparison

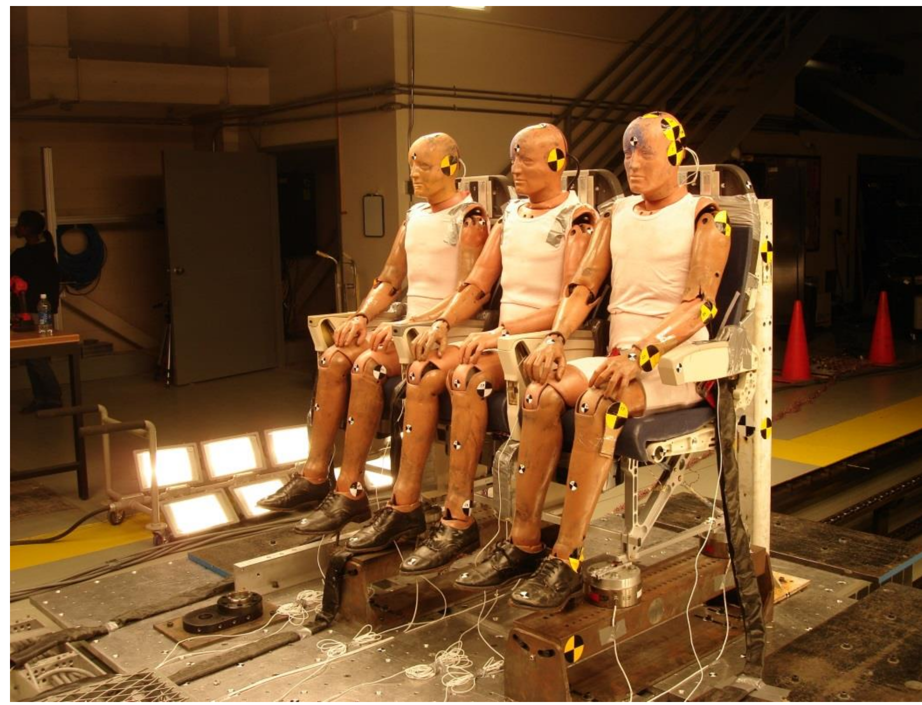


Certification by Analysis

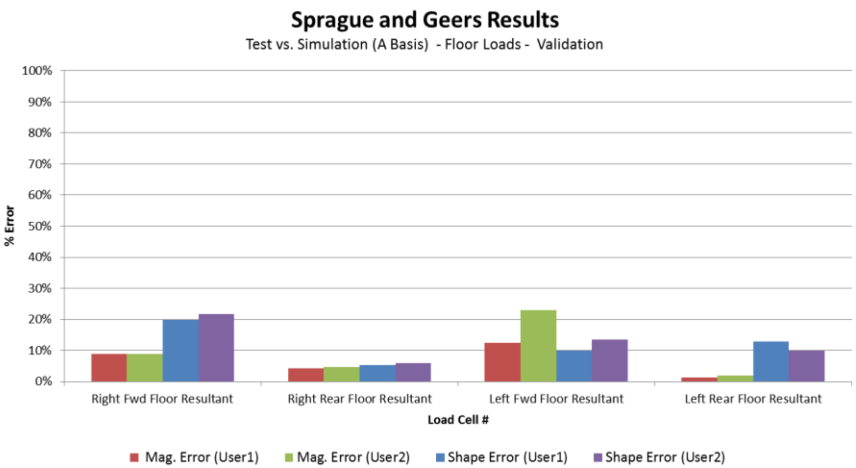
Numerical Analysis
Head Path Configuration

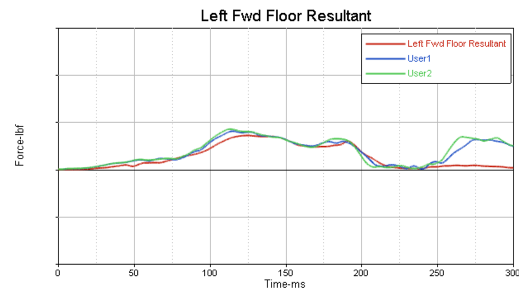
Head Path Test (08102 – 1)

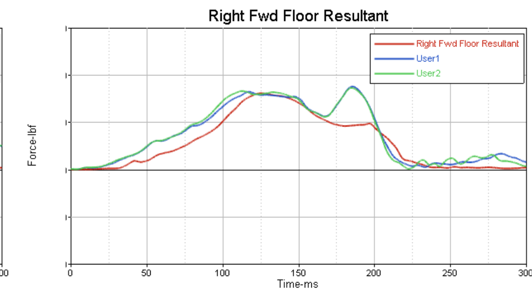
- Test Condition
  - Three Passengers Economy Aircraft Seat
  - Standard 2-pt Belt
  - FAA 25.562 - Pitch - 0 deg. - Roll - 0 deg. - Yaw 0 deg.

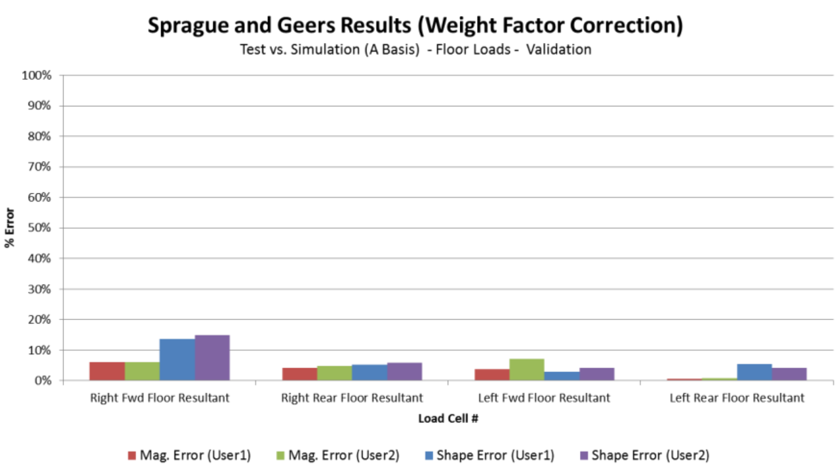


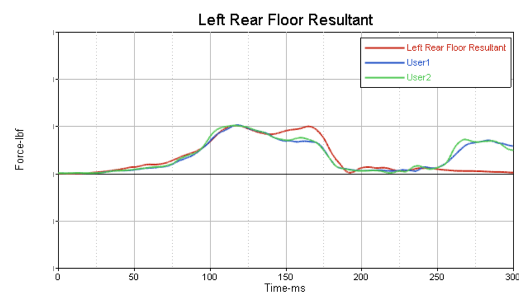
Floor Loads – Sprague and Geers

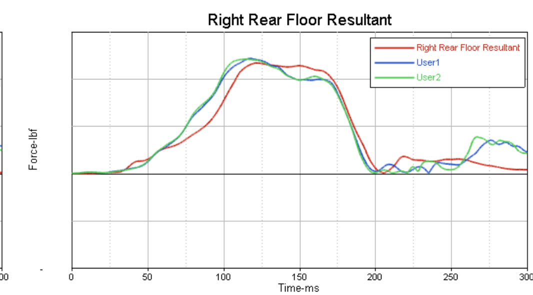




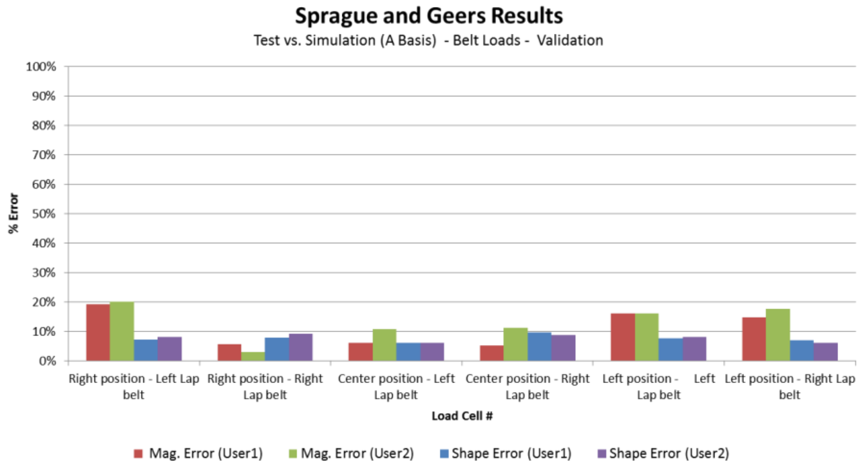


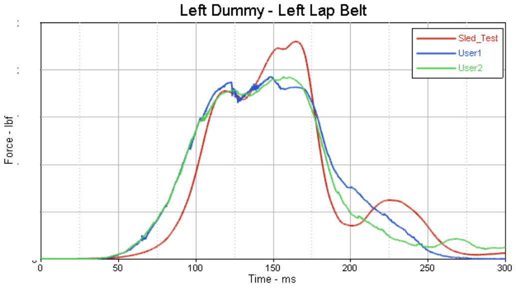


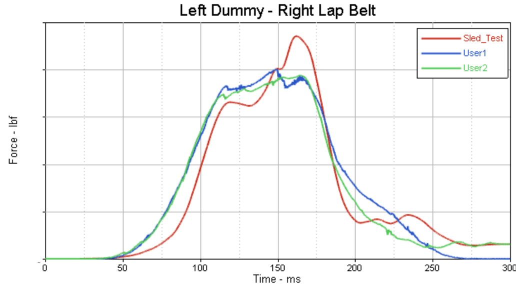


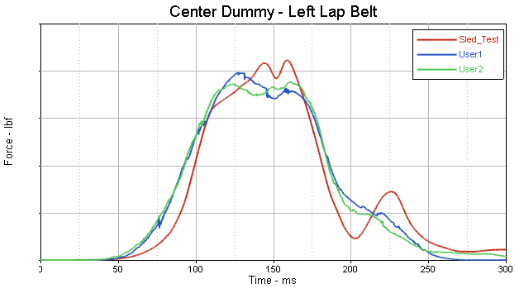


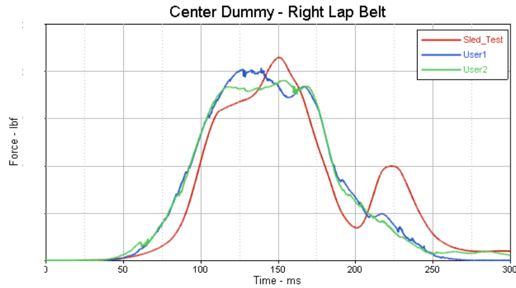
Belt Loads – Sprague and Geers

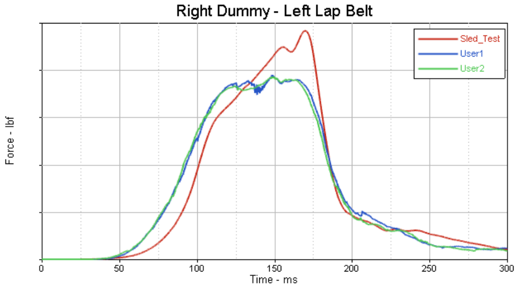


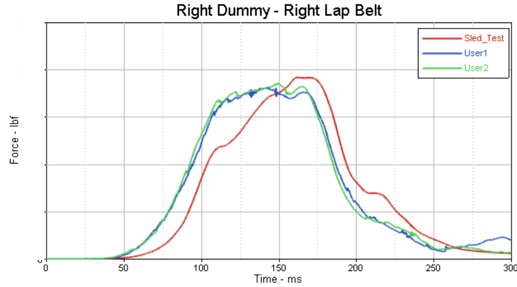












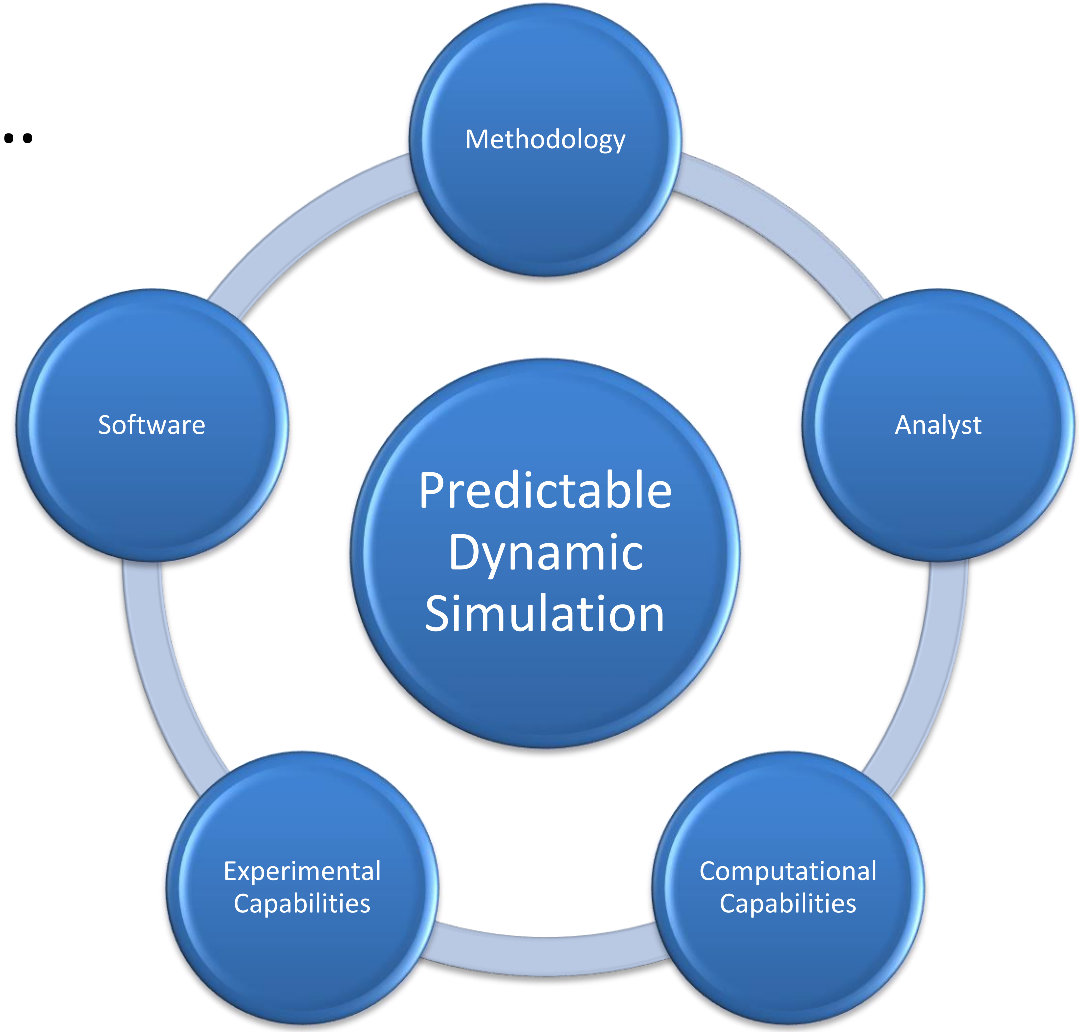
Head Path – Kinematics Comparison

Certification by Analysis

Numerical Analysis Future

Can we have predictable simulations today?

Yes, if……



Thank you for your attention

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