Numerical Aerospace ATD Validation and Testing Procedures

G. Olivares, J. Guarddon
The Fifth Triennial International Aircraft Fire and Cabin Safety Research Conference, Atlantic City
October 30th 2007
Certification by Analysis - Motivation

The development of aircraft interiors is driven by individualized customer demands, increasingly complex products and ever shorter innovation cycles. To cope with these challenges, a company must be able to deliver in a timely manner high quality customized interiors that meet their customers specifications and the applicable certification requirements. Aircraft manufacturers are under strong pressure to reduce costs and development cycles in a highly competitive market. To remain competitive in today’s market, aircraft manufacturers must conduct research in the development of state-of-the-art computational tools and processes in order to reduce the amount of physical testing, certification costs and product development cycles.
AC 20-146 - Scope

- This document defines the acceptable applications, limitations, validation processes, and minimum documentation requirements involved when substantiation by computer modeling is used to support a seat certification program.

- Computer modeling analytical techniques may be used to do the following, provided all pass/fail criteria identified in §§ 23.562, 25.562, 27.562, or 29.562 are satisfied:
  - Establish the critical seat installation/configuration in preparation for dynamic testing.
  - Demonstrate compliance to §§ 23.562, 25.562, 27.562, or 29.562 for changes to a baseline seat design, where the baseline seat design has demonstrated compliance to these rules by dynamic tests. Changes may include geometric or material changes to primary and non-primary structure.

- AC 20-146 does not specify the validation metric and criteria for the numerical ATDs.
Technical Approach

- **Phase I: Numerical Anthropometric Test Dummies:**
  - Literature review and numerical tools survey
  - Baseline sled testing – Rigid Seat:
    - Test variability studies – Establish validation criteria
    - Comparison performance HII and HIII FAA ATDs
  - Simulation studies:
    - Survey numerical ATD database availability
    - Preliminary evaluation of numerical ATDs with sled test data for part 25.562 pulses
    - Stochastic and/or DOE numerical model evaluation
  - Model Validation Methodology:
    - Validation metrics methods: review and evaluation
    - Identify data channels required, and validation criteria
Numerical ATD Validation Process

- Numerical ATD Certification
- ATD Component Testing Validation
- ATD Application Testing Validation
Component Level Validation

Numerical ATD Calibration

Virtual ATD Calibration Testing

Component Numerical Calibration

Head Drop, Knee Impact…

Numerical Model Calibration Report

Define Additional Component Tests

Physical Model Calibration Report

Physical ATD Calibration Testing

Component Calibration Testing
Application Level Validation

ATD Application Testing Validation

0 deg – 2, 3 and 4 Point Restraint – Rigid Seat

- Head Path
- Head Acceleration
- Belt Forces
- Seat Transfer Forces

60 deg – 2 Point Restraint – Rigid Seat without Cushion

- Lumbar Load
- Seat Transfer Forces

60 deg – 2 Point Restraint – Rigid Seat with Cushion

- Lumbar Load
- Seat Transfer Forces
## Test Configurations

<table>
<thead>
<tr>
<th>TEST NUMBER</th>
<th>ATD Serial#</th>
<th>BELT TYPE</th>
<th>TEST ANGLE (deg)</th>
<th>LOADING</th>
<th>SEAT TYPE</th>
<th>BELT MATERIAL</th>
<th>CRASH PULSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>06165-1</td>
<td>FAA HYB III 290</td>
<td>2</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-2</td>
<td>FAA HYB III 290</td>
<td>2</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-3</td>
<td>HYB II 698</td>
<td>2</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-4</td>
<td>HYB II 698</td>
<td>2</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-5</td>
<td>HYB II 698</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-6</td>
<td>HYB II 698</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-7</td>
<td>FAA HYB III 289</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-8</td>
<td>FAA HYB III 289</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-9</td>
<td>EMPTY</td>
<td>-</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>-</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-10</td>
<td>HYB II 656</td>
<td>3</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-11</td>
<td>HYB II 656</td>
<td>3</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-12</td>
<td>FAA HYB III 289</td>
<td>3</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-13</td>
<td>FAA HYB III 289</td>
<td>3</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-14</td>
<td>FAA HYB III 289</td>
<td>4</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-15</td>
<td>FAA HYB III 289</td>
<td>4</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-16</td>
<td>EMPTY</td>
<td>-</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>-</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-17</td>
<td>HYB II 656</td>
<td>4</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-18</td>
<td>HYB II 656</td>
<td>4</td>
<td>0</td>
<td>16g</td>
<td>Rigid</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-19*</td>
<td>HYB II 655</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Cushioned</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-20</td>
<td>HYB II 655</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Cushioned</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-21</td>
<td>FAA HYB III 289</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Cushioned</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-22</td>
<td>FAA HYB III 289</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Cushioned</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
<tr>
<td>06165-23**</td>
<td>FAA HYB III 290</td>
<td>2</td>
<td>60</td>
<td>14g</td>
<td>Cushioned</td>
<td>100% Polyester</td>
<td>25.562</td>
</tr>
</tbody>
</table>
NIAR Servo-Hydraulic Sled Testing
# Test Data Channels and Polarities Overview

<table>
<thead>
<tr>
<th>Channel Description</th>
<th>Channel Units</th>
<th>Hybrid II</th>
<th>Hybrid III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sled acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Head X acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Head Y acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Head Z acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Upper neck force X direction</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Upper neck force Y direction</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Upper neck force Z direction</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Upper neck moment about X axis</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Upper neck moment about Y axis</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Upper neck moment about Z axis</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Torso X acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Torso Y acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Torso Z acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lumbar load X direction</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lumbar load Z direction</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lumbar moment about Y axis</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Pelvis X acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Pelvis Y acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Pelvis Z acceleration</td>
<td>G's vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Left femur compression load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Right femur compression load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lap strap left side tension load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Lap strap right side tension load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Shoulder left strap tension load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Shoulder right strap tension load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Joint shoulder straps tension load</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat back X reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat back Y reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat back Z reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat pan X reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat pan Y reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat pan Z reaction force</td>
<td>Lbf vs Sec</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Seat pan X reaction moment</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Seat pan Y reaction moment</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Seat pan Z reaction moment</td>
<td>In-lbf vs Sec</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Head trajectory in the X-Z plane</td>
<td>Inch vs Inch</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Chest trajectory in the X-Z plane</td>
<td>Inch vs Inch</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Torso trajectory in the X-Z plane</td>
<td>Inch vs Inch</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Knee trajectory in the X-Z plane</td>
<td>Inch vs Inch</td>
<td>√</td>
<td>√</td>
</tr>
</tbody>
</table>
Sled Test Setup: Pre-Test Measurements

Side View of ATD Targets

- Head (#2)
- Shoulder (#6)
- Knee (#3)
- Hip (#1)
- Ankle (#4)
**Validation Metrics Evaluation**

- Computable measures are needed that can **quantitatively** compare experimental and computational results over a series of parameters to **objectively** assess computational accuracy over the traditional qualitative graphical comparison.
- **Applications:**
  - Quantify repeatability of test results (Establish physical test variability corridors)
  - Numerical model quality evaluation
- **Four validation metrics methods have been evaluated:**
  - Sprague & Geers validation metric
  - Weighted Integration Factor validation metric
  - Quick Rating from MADPost Software (includes 3 different metric evaluations)
  - Mod Eval Software (includes 4 different metric evaluations)

![Graphs of Magnitude Error, Phase Error, and Area Under Curve Error](image-url)
Validation Metric: Sprague and Geers

\[
\begin{align*}
\mathcal{G}_{bb} &= \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} b^2(t) dt \\
\mathcal{G}_{cc} &= \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} c^2(t) dt \\
\mathcal{G}_{bc} &= \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} b(t)c(t) dt
\end{align*}
\]

\[
P = \frac{1}{\pi} \cos^{-1} \left( \frac{\mathcal{G}_{bc}}{\mathcal{G}_{bb} \mathcal{G}_{cc}} \right) \\
M = \sqrt{\mathcal{G}_{cc}} / \mathcal{G}_{bb} - 1 \\
C = \sqrt{M^2 + P^2}
\]

Where;

\( t_1 < t < t_2 \) evaluation period
\( b(t) = \) reference data
\( c(t) = \) data to compare
\( P = \) phase error
\( M = \) magnitude error
\( C = \) comprehensive error (S&G score)
Notes:
1. The bar or column height corresponds to the average value obtained from all tests for that channel.
2. The brackets shown on each bar extend from the minimum response value to the maximum for that particular channel.
**HII ATD Compliance Channels - FAR 25.562 – 0 deg**

### HII ATD Compliance Responses (Average 0° Tests)

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Ar</td>
<td>22%</td>
</tr>
<tr>
<td>Lumbar Fz</td>
<td>5%</td>
</tr>
<tr>
<td>Left Lap</td>
<td>10%</td>
</tr>
<tr>
<td>Right Lap</td>
<td>15%</td>
</tr>
<tr>
<td>Shoulder Belt 1</td>
<td>20%</td>
</tr>
<tr>
<td>Shoulder Belt 2</td>
<td>25%</td>
</tr>
<tr>
<td>Shoulder Belt 3</td>
<td>30%</td>
</tr>
<tr>
<td>Seat Pan Res</td>
<td>35%</td>
</tr>
<tr>
<td>Head Excursion</td>
<td>40%</td>
</tr>
</tbody>
</table>

**Head Excursion Errors are calculated from:**

\[
\text{HeadExcursionError} = \sqrt{\text{HeadPath}_Z\_Error^2 + \text{HeadPath}_X\_Error^2}
\]
HII ATD Compliance Channels- FAR 25.562 – 60 deg

HII ATD COMPLIANCE RESPONSES (AVERAGE 60º TESTS)

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>Mag. Error</th>
<th>Phase Error</th>
<th>Total Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Ar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumbar Fz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left Lap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right Lap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seat Pan Res</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Notes:
1. The bar or column height corresponds to the average value obtained from all tests for that channel.
2. The brackets shown on each bar extend from the minimum response value to the maximum for that particular channel.
HIII FAA ATD Compliance Channels- FAR 25.562 – 0 deg

HIII ATD COMPLIANCE RESPONSES (AVERAGE 0º TESTS)

Channel:
- Head Ar
- Lumbar Fz
- Left Lap
- Right Lap
- Shoulder Belt 1
- Shoulder Belt 2
- Shoulder Belt 3

Error Levels:
- Mag. Error
- Phase Error
- Total Error

The diagram shows the compliance responses for different channels with average 0º tests.
HIII FAA ATD Compliance Channels - FAR 25.562 – 60 deg

HIII ATD COMPLIANCE RESPONSES (AVERAGE 60° TESTS)

CHANNEL
Mag. Error  Phase Error  Total Error

0%  5%  10%  15%  20%  25%  30%
Validation Example: HIII FAA FAR 25.562
Validation Example I: Sample Responses

- **Head CG Resultant - Acceleration**
  - Magnitude Error: 4%
  - Phase Error: 8%
  - Comprehensive Error: 8%

- **Torso Resultant - Acceleration**
  - Magnitude Error: 4%
  - Phase Error: 7%
  - Comprehensive Error: 7%

- **Pelvic Resultant - Acceleration**
  - Magnitude Error: 6%
  - Phase Error: 7%
  - Comprehensive Error: 7%

- **Lumbar Z - Force**
  - Magnitude Error: 1%
  - Phase Error: 21%
  - Comprehensive Error: 21%
Validation Example I: Sample Responses

Seat Pan X - Force (global coordsys)

Seat Pan Y - Force

Seat Pan Z - Force (global coordsys)

Seat Pan Resultant Force
## Validation Example I: Validation Metric (S&G)

<table>
<thead>
<tr>
<th>CHANNEL</th>
<th>TEST CONDITION</th>
<th>MAGNITUDE ERROR</th>
<th>PHASE ERROR</th>
<th>COMBINED</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEAD RESULTANT ACCELERATION</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td>5%</td>
<td>4%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>4%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>SEAT PAN REACTION FORCE X</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td>5%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEAT PAN REACTION FORCE Y</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td>-5%</td>
<td>22%</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>-55%</td>
<td>45%</td>
<td>71%</td>
</tr>
<tr>
<td>SEAT PAN REACTION FORCE Z</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td></td>
<td>1.01%</td>
<td>1.01%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>26%</td>
<td>20%</td>
<td>33%</td>
</tr>
<tr>
<td>SEAT PAN REACTION FORCE RESULTANT</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td></td>
<td>1.00%</td>
<td>1.34%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>6%</td>
<td>7%</td>
<td>9%</td>
</tr>
<tr>
<td>LAP BELT REACTION FORCE LEFT</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td></td>
<td>5%</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>118%</td>
<td>22%</td>
<td>120%</td>
</tr>
<tr>
<td>LUMBAR LOAD</td>
<td>TEST vs. TEST</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-7)</td>
<td>0.65%</td>
<td>1.27%</td>
<td>1.36%</td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 POINT BELT, 60° (06165-6)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TEST vs. Simulation 2 POINT BELT, 0° (SIMULATION)</td>
<td>1%</td>
<td>21%</td>
<td>21%</td>
</tr>
</tbody>
</table>
Validation Example I: Occupant Kinematics
Validation Example I: Occupant Kinematics
Validation Example I: Occupant Kinematics
Validation Example I: Occupant Kinematics
Validation Example I: Occupant Kinematics
Validation Example I: Occupant Kinematics
Validation Example II: Sample Responses

Torso Resultant - Acceleration

Lumbar Z - Force

Pelvic Resultant - Acceleration
Validation Example II: Model Sensitivity Study

• Study the effect of modeling parameters:
  – Webbing Characteristics: 5% / 8% / 10%
  – Seat/ATD Friction: 0 / 0.3 / 0.6
  – Belt/ATD Friction: 0 / 0.3 / 0.6
  – Feet ATD/Ground Plane: 0 / 0.5 / 1.0

• Design of Experiment Setup:
  – Number of Discrete Factors: 4
  – Number of Responses: 25
  – Total Runs: 81
  – Model Complexity: Least Square
  – Model Resolution: Quadratic
  – Number of Terms: 33
  – DOE Type: Full Factorial (Mixed Levels)
Val. Example II: Sample Lumbar Load Sensitivity
Val. Example II: Sample Lumbar Load Sensitivity
Validation Example II: Occupant Kinematics
Validation Example II: Occupant Kinematics
Conclusion

- A set of test data is available to numerical ATD developers and the aerospace industry to evaluate numerical ATD performance.
- Sprague and Geers validation metric provide an objective method to quantitatively compare experimental and computational results over a series of parameters.
- The test variability data obtained during this project may be used in the future to establish ATD numerical model validation criteria.
- Preliminary simulation studies indicate that current ATD Databases (Multibody and Finite Element) need improvement in the abdomen/belt interaction area in order to improve the accuracy of head and pelvis kinematics, as well as lap belt reaction forces.

Future work:
  - SAE Seat Committee CBA Working Group to define ARP document with validation metric and criteria.
  - System level computational Stochastic and DOE analyses:
    • Eliminate deterministic models and designs hence improving the “robustness” of the designs
  - Research additional applications such as row-to-row, bulkhead, HUD installations, and side facing seats
  - Develop Virtual Certification protocols
A Look Forward