Numerical Aerospace ATD Validation and Testing Procedures

G. Olivares, J. Guarddon

The Fifth Triennial International Aircraft Fire and Cabin Safety Research Conference, Atlantic City

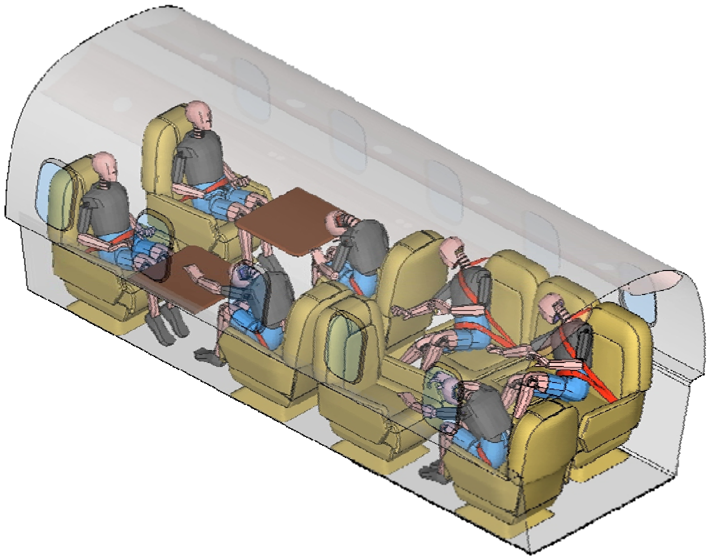
October 30th 2007

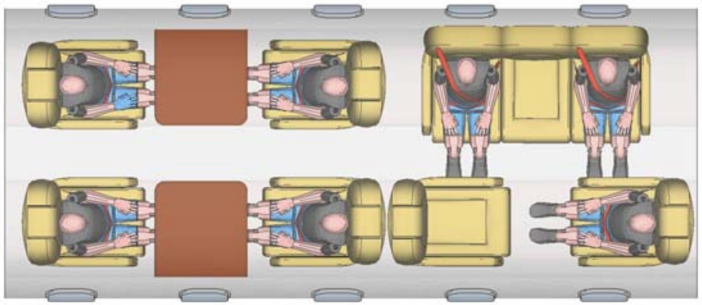
Certification by Analysis - Motivation

- 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

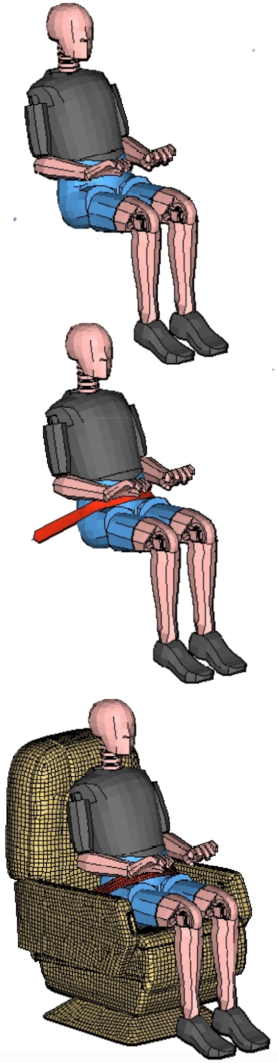
- This document defines the acceptable applications, limitations, validation processes, and minimum documentation requirements involved when substantiation by computer modeling is used to support a seat certification program.
- Computer modeling analytical techniques may be used to do the following,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

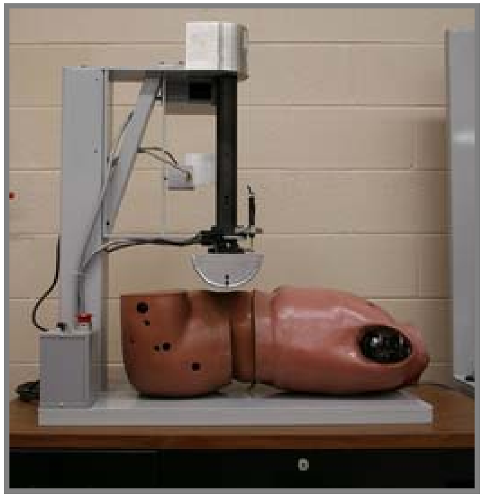
- **Phase I: Numerical Anthropometric Test Dummies:**
  - Literature review and numerical tools survey
  - Baseline sled testing – Rigid Seat:
    - Test variability studies – Establish validation criteria
    - Comparison performance HII and HIII FAA ATDs
  - Simulation studies:
    - Survey numerical 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

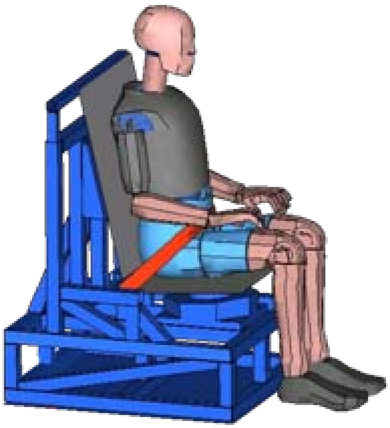


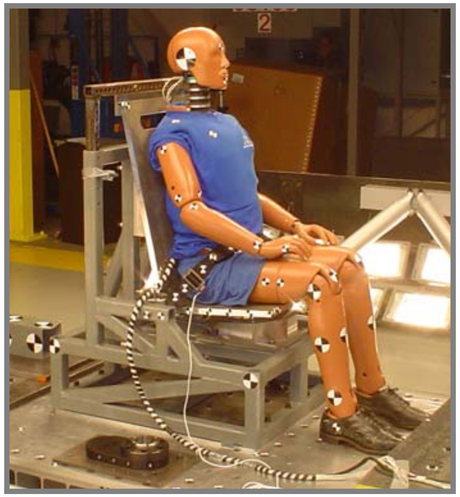
Numerical ATD Validation Process

Numerical ATD Certification

- ATD Component Testing Validation
- ATD Application Testing Validation







Component Level Validation

Numerical ATD Calibration

Virtual ATD Calibration Testing

Component Numerical Calibration

Physical ATD Calibration Testing

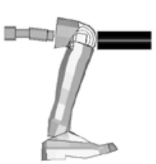
Component Calibration Testing

Head Drop, Knee Impact…

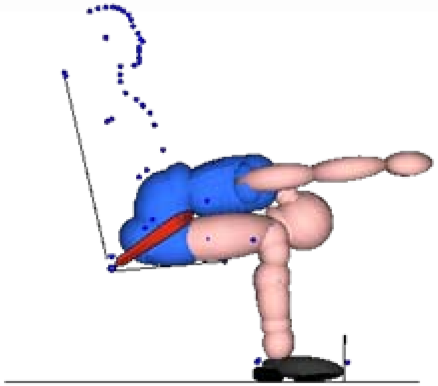
Numerical Model Calibration Report

Define Additional Component Tests

Physical Model Calibration Report



Application Level Validation



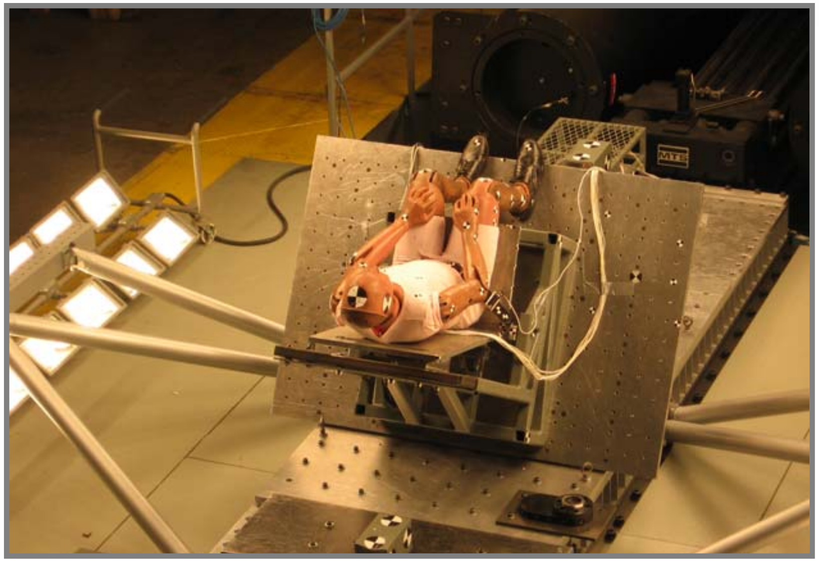
ATD Application Testing Validation

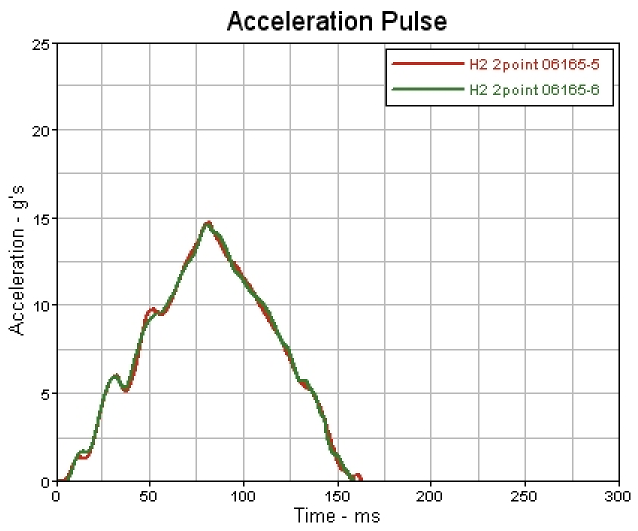
0 deg – 2, 3 and 4 Point Restraint – Rigid Seat	60 deg – 2 Point Restraint – Rigid Seat without Cushion	60 deg – 2 Point Restraint – Rigid Seat with Cushion
Head Path **Head Acceleration** **Belt Forces** **Seat Transfer Forces**	**Lumbar Load** **Seat Transfer Forces**	**Lumbar Load** **Seat Transfer Forces**

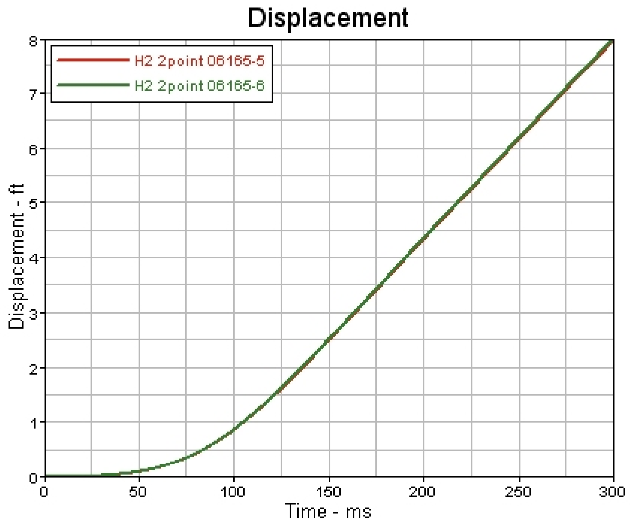
Test Configurations

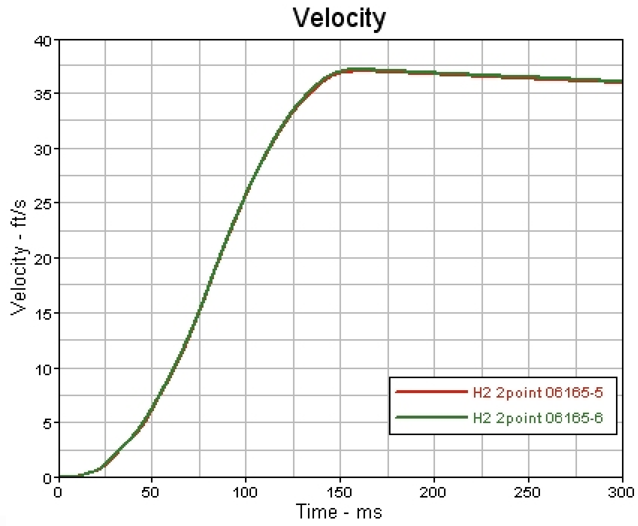
TEST NUMBER	ATD Serial#	BELT TYPE	TEST ANGLE (deg)	LOADING	SEAT TYPE	BELT MATERIAL	CRASH PULSE
06165-1	FAA HYB III 290	2	0	16g	Rigid	100% Polyester	25.562
06165-2	FAA HYB III 290	2	0	16g	Rigid	100% Polyester	25.562
06165-3	HYB II 698	2	0	16g	Rigid	100% Polyester	25.562
06165-4	HYB II 698	2	0	16g	Rigid	100% Polyester	25.562
06165-5	HYB II 698	2	60	14g	Rigid	100% Polyester	25.562
06165-6	HYB II 698	2	60	14g	Rigid	100% Polyester	25.562
06165-7	FAA HYB III 289	2	60	14g	Rigid	100% Polyester	25.562
06165-8	FAA HYB III 289	2	60	14g	Rigid	100% Polyester	25.562
06165-9	EMPTY	-	0	16g	Rigid	-	25.562
06165-10	HYB II 656	3	0	16g	Rigid	100% Polyester	25.562
06165-11	HYB II 656	3	0	16g	Rigid	100% Polyester	25.562
06165-12	FAA HYB III 289	3	0	16g	Rigid	100% Polyester	25.562
06165-13	FAA HYB III 289	3	0	16g	Rigid	100% Polyester	25.562
06165-14	FAA HYB III 289	4	0	16g	Rigid	100% Polyester	25.562
06165-15	FAA HYB III 289	4	0	16g	Rigid	100% Polyester	25.562
06165-16	EMPTY	-	0	16g	Rigid	-	25.562
06165-17	HYB II 656	4	0	16g	Rigid	100% Polyester	25.562
06165-18	HYB II 656	4	0	16g	Rigid	100% Polyester	25.562
06165-19*	HYB II 655	2	60	14g	Cushioned	100% Polyester	25.562
06165-20	HYB II 655	2	60	14g	Cushioned	100% Polyester	25.562
06165-21	FAA HYB III 289	2	60	14g	Cushioned	100% Polyester	25.562
06165-22	FAA HYB III 289	2	60	14g	Cushioned	100% Polyester	25.562
06165-23**	FAA HYB III 290	2	60	14g	Cushioned	100% Polyester	25.562

NIAR Servo-Hydraulic Sled Testing



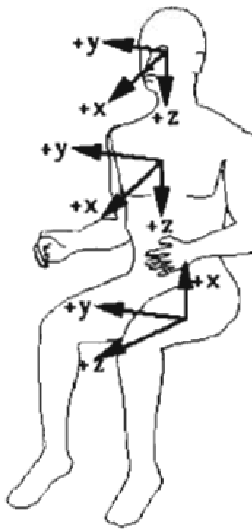




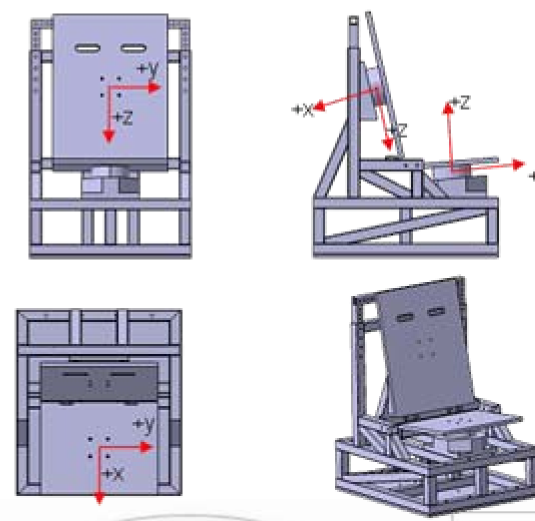


Test Data Channels and Polarities Overview

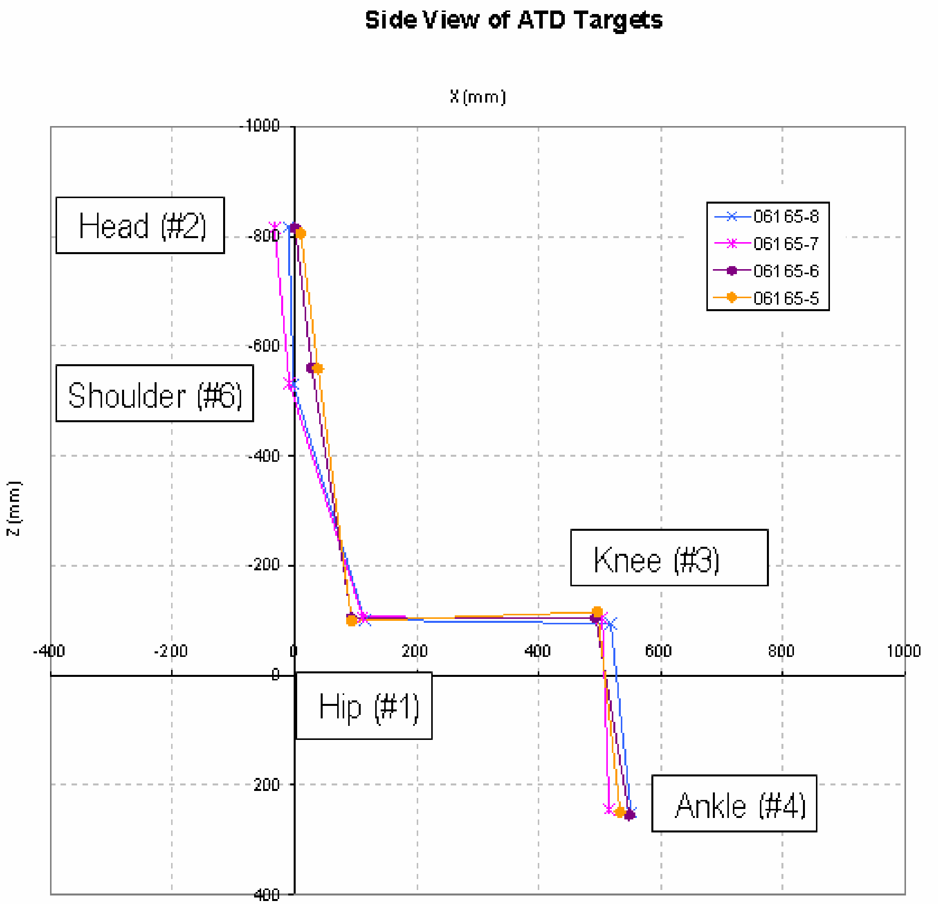
Channel Description	Channel Units	Hybrid II	Hybrid III
Sled acceleration	G's vs Sec	√	√
Head X acceleration	G's vs Sec	√	√
Head Y acceleration	G's vs Sec	√	√
Head Z acceleration	G's vs Sec	√	√
Upper neck force X direction	Lbf vs Sec		√
Upper neck force Y direction	Lbf vs Sec		√
Upper neck force Z direction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

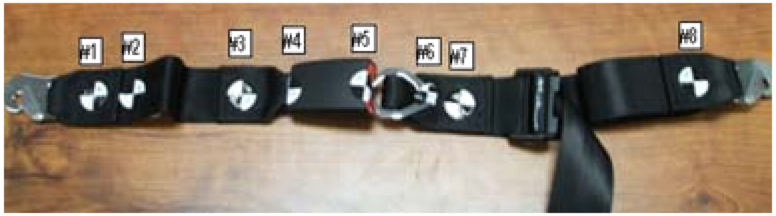


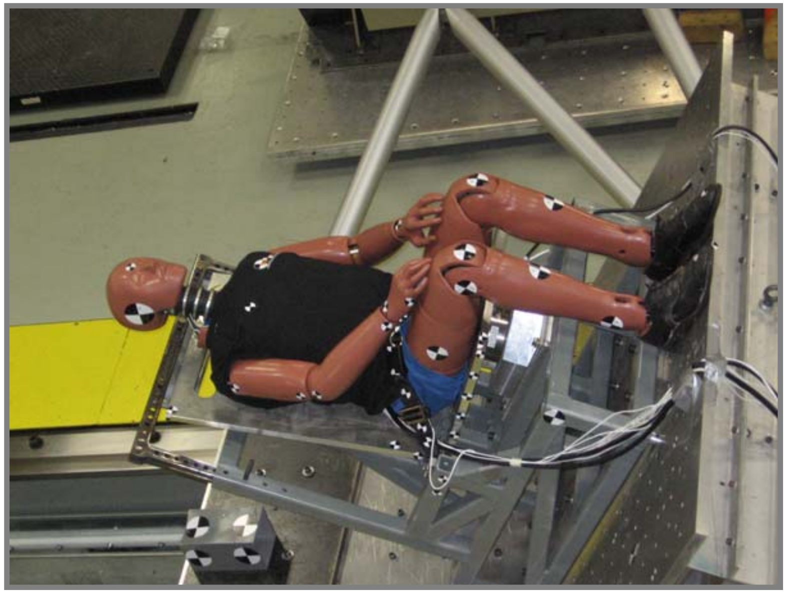
SAE J211-1



Sled Test Setup: Pre-Test Measurements



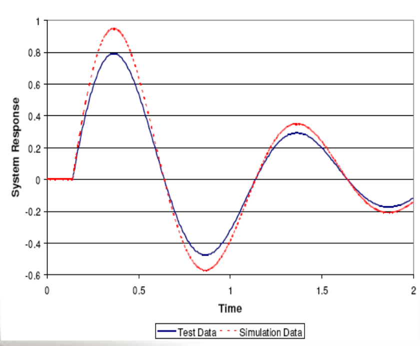




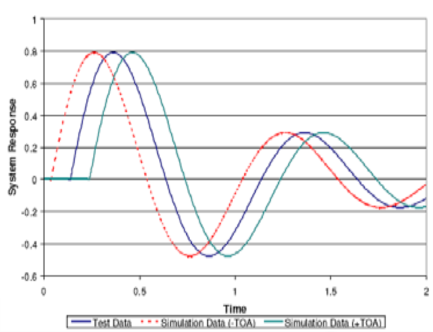
Validation Metrics Evaluation

- 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)

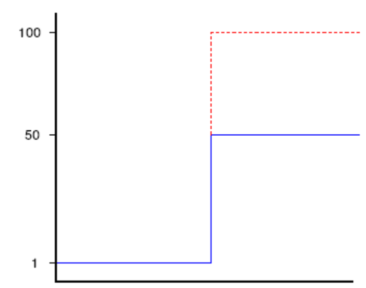
Magnitude Error



Phase Error



Area Under Curve Error



Validation Metric: Sprague and Geers

$$\vartheta_{bb} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} b^2(t)dt$$

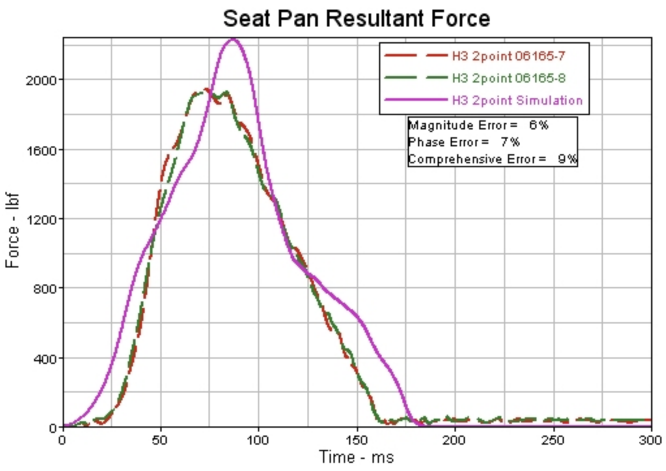
$$\vartheta_{cc} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} c^2(t)dt$$

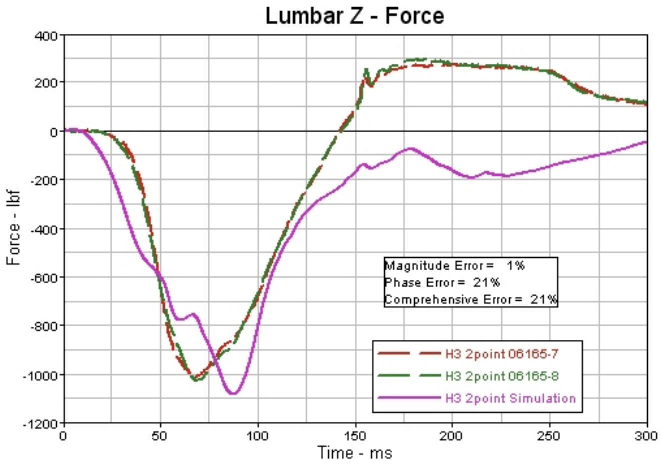
$$\vartheta_{bc} = \frac{1}{t_2 - t_1}\int_{t_1}^{t_2} b(t)c(t)dt$$

$$P = \frac{1}{\pi}\cos^{-1}(\vartheta_{bc} / \sqrt{\vartheta_{bb}\vartheta_{cc}})$$

$$M = \sqrt{\vartheta_{cc} / \vartheta_{bb}} - 1$$

$$C = \sqrt{M^2 + P^2}$$

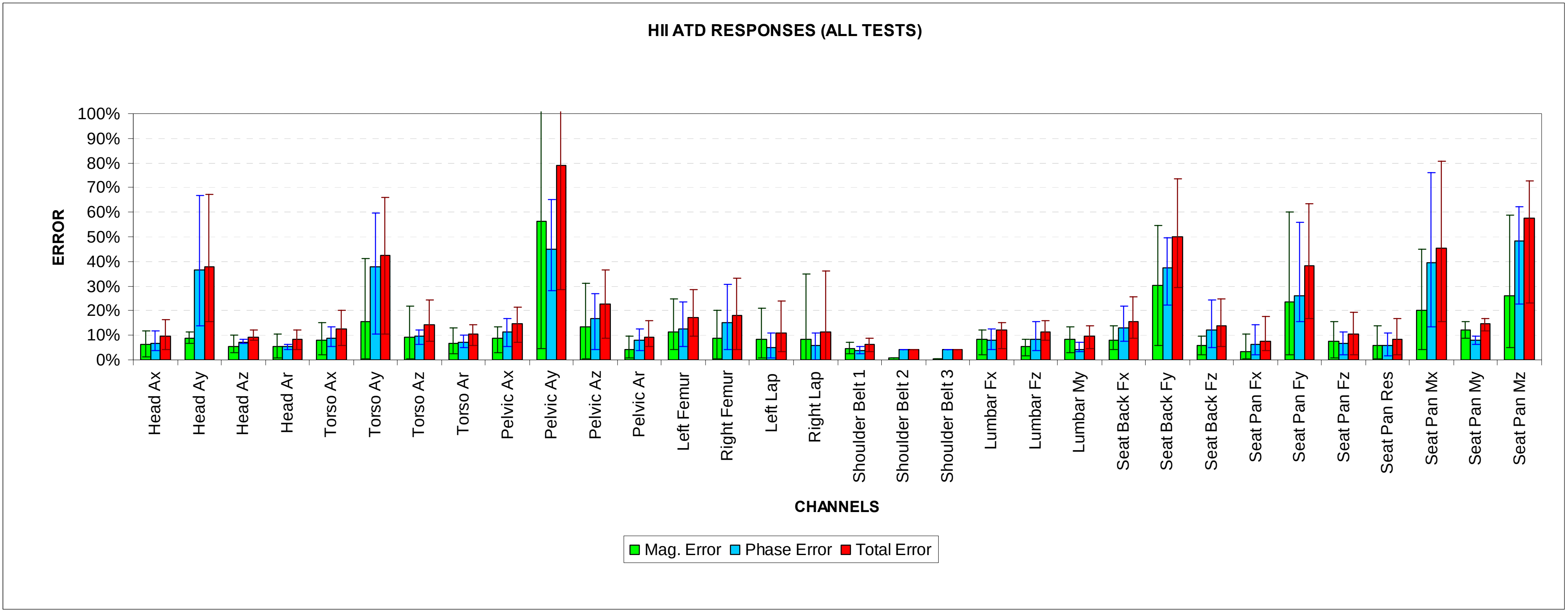




Where;

t1<t<t2 evaluation period
b(t) = reference data
c(t) = data to compare
P = phase error
M = magnitude error
C = comprehensive error (S&G score)

HII ATD all Sled Test Conditions

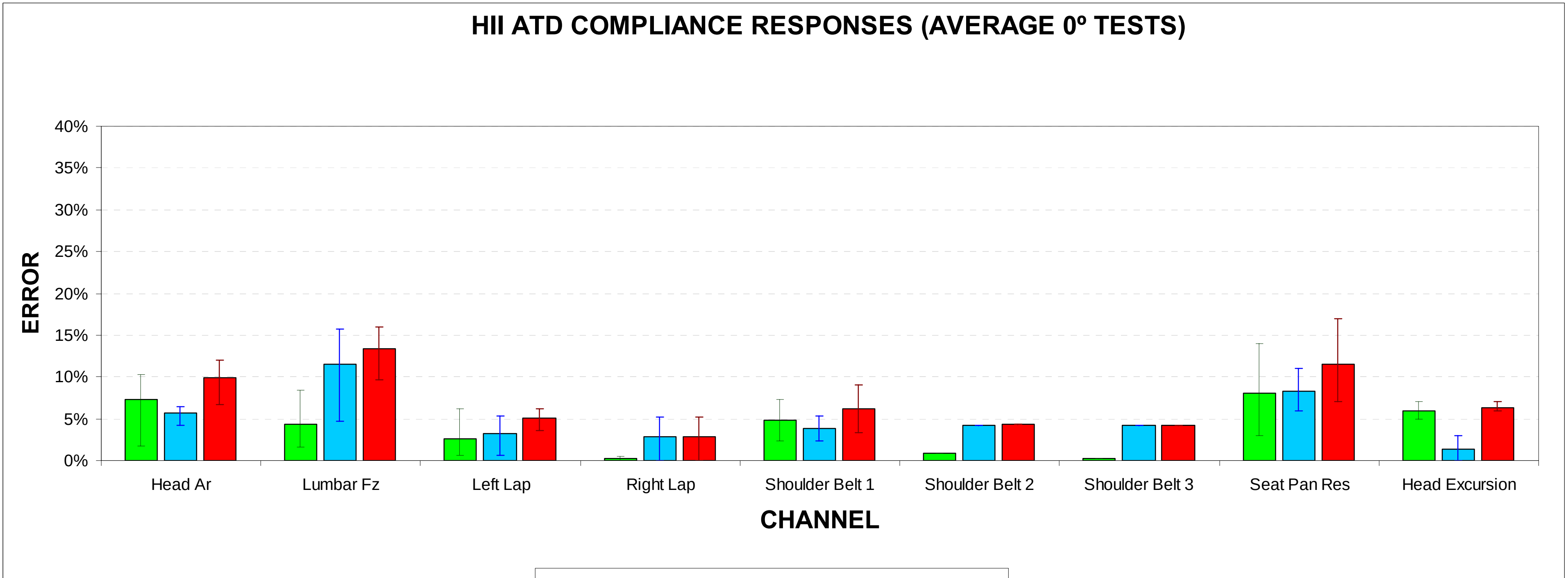


Notes:

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.

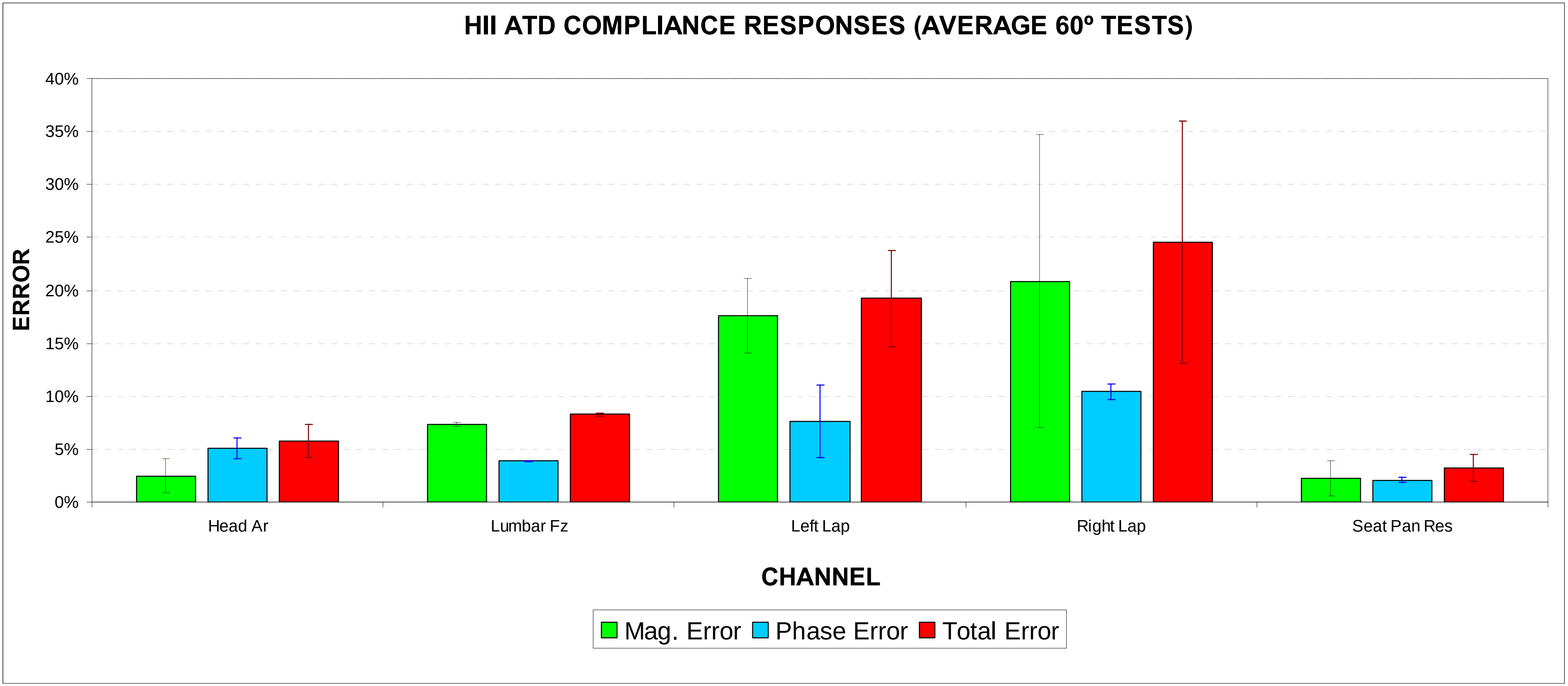
HII ATD Compliance Channels- FAR 25.562 – 0 deg



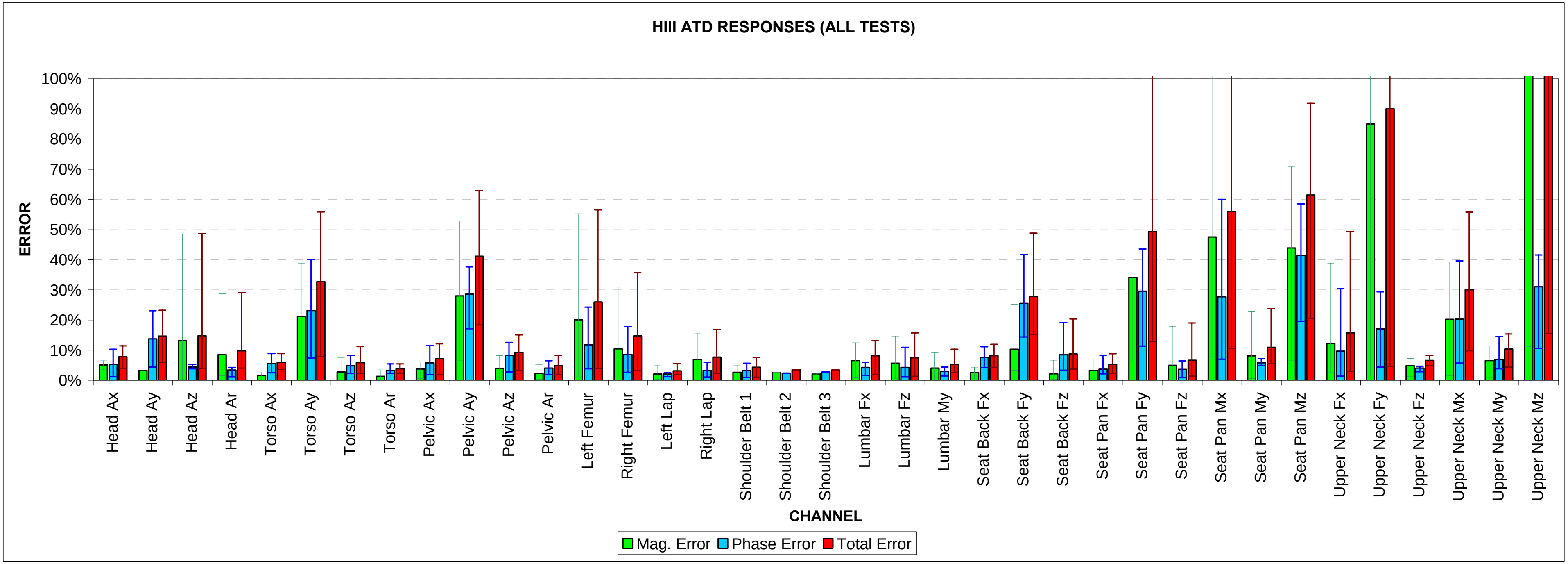
* Head Excursion Errors are calculated from:

$$HeadExcursionError = \sqrt{HeadPath\_Z\_Error^2 + HeadPath\_X\_Error^2}$$

HII ATD Compliance Channels- FAR 25.562 – 60 deg



HIII FAA ATD all Sled Test Conditions

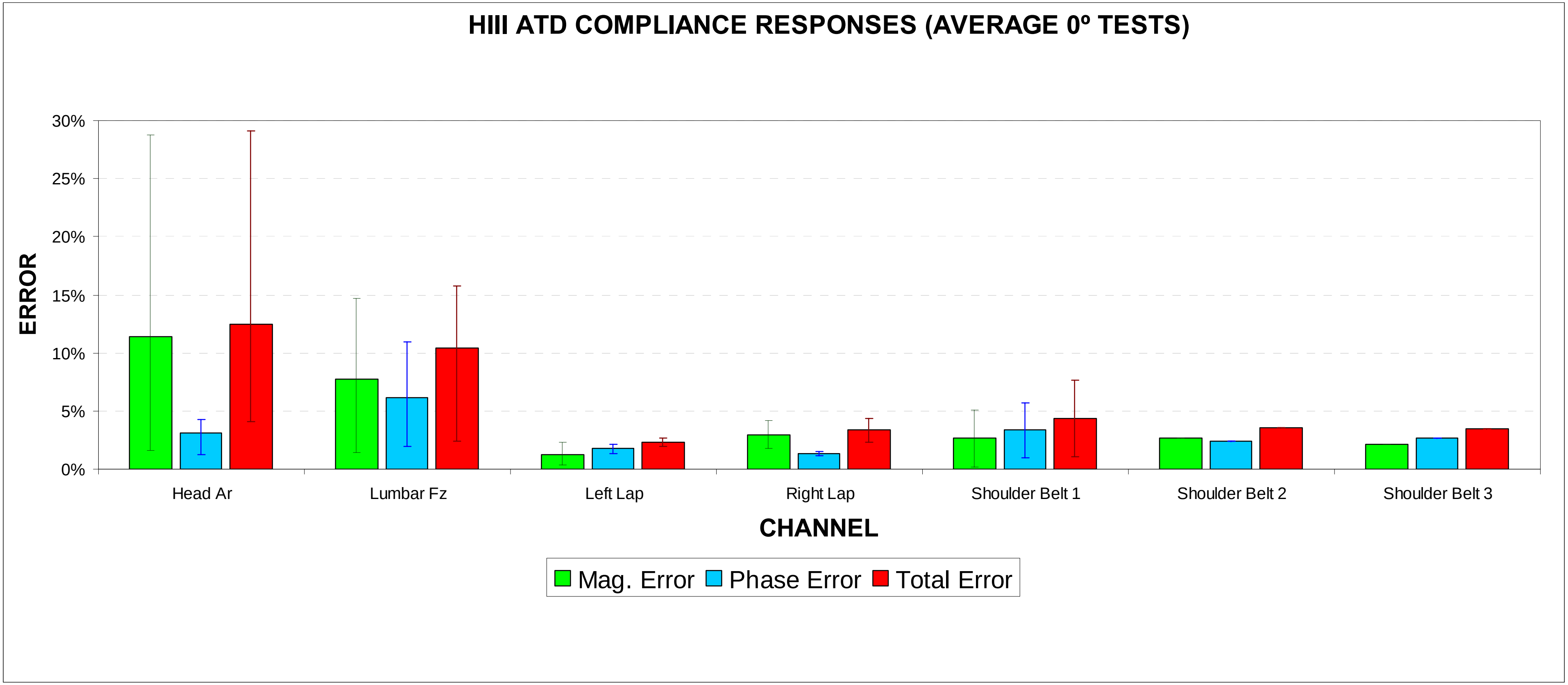


Notes:

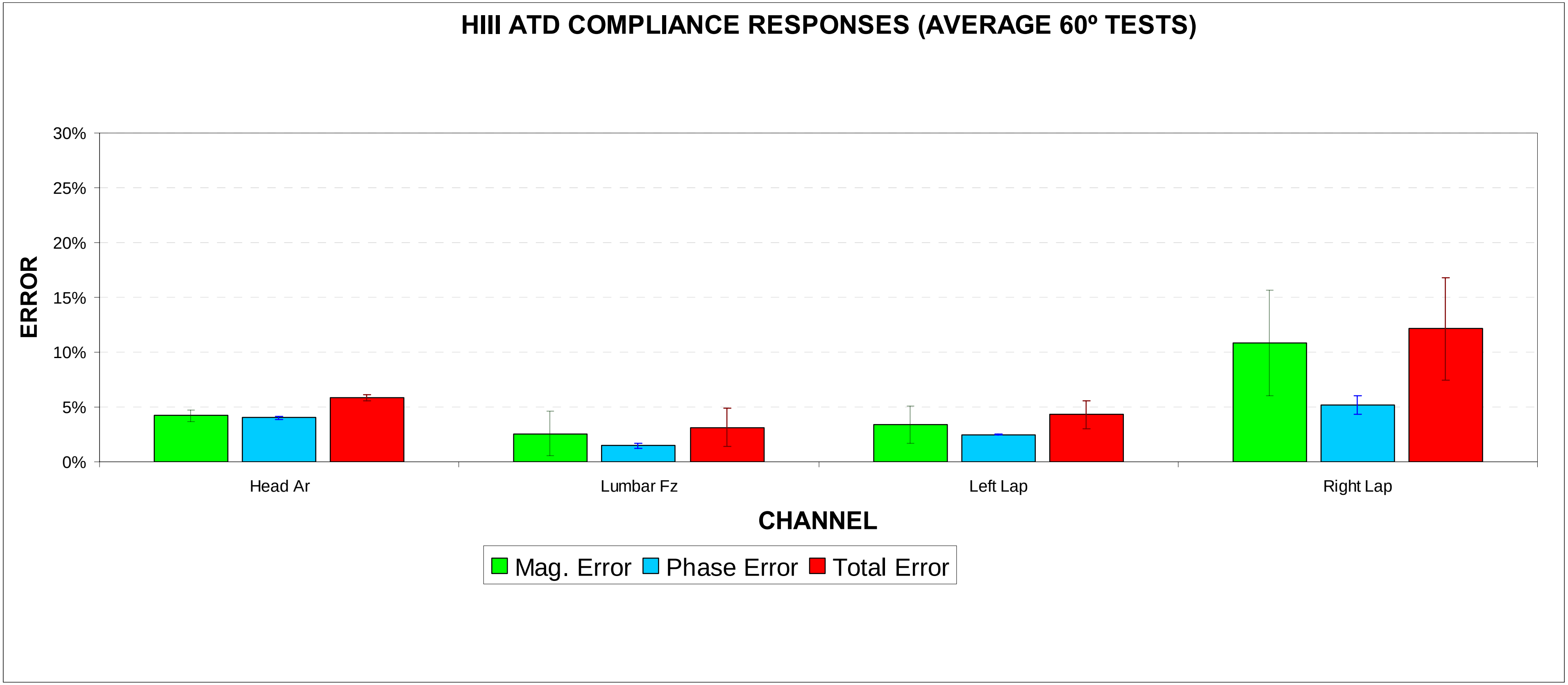
1.The bar or column height corresponds to the average value obtained from all tests for that channel.

2.The brackets shown on each bar extend from the minimum response value to the maximum for that particular channel.

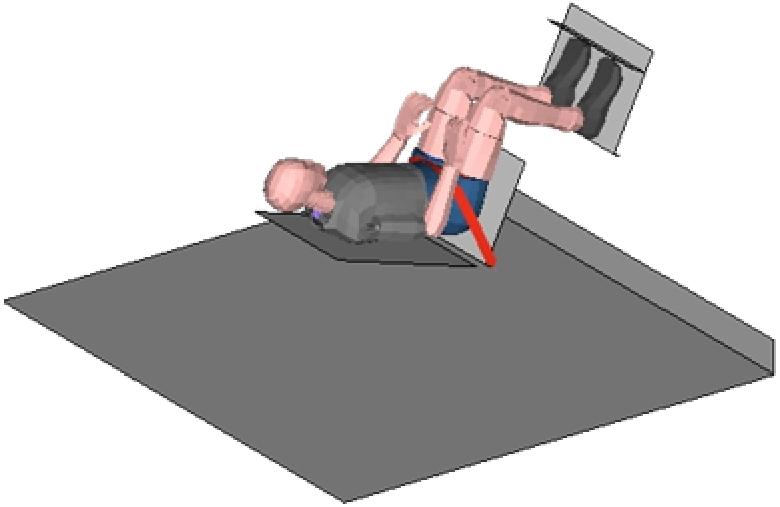
HIII FAA ATD Compliance Channels- FAR 25.562 – 0 deg

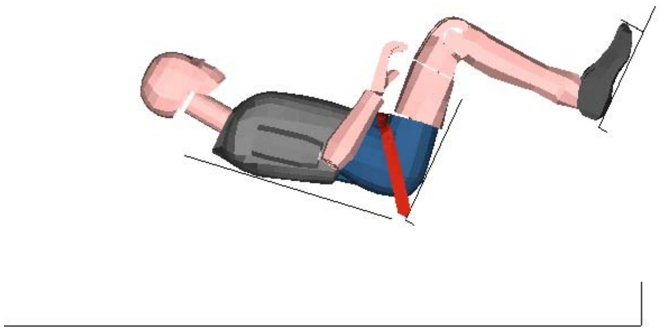


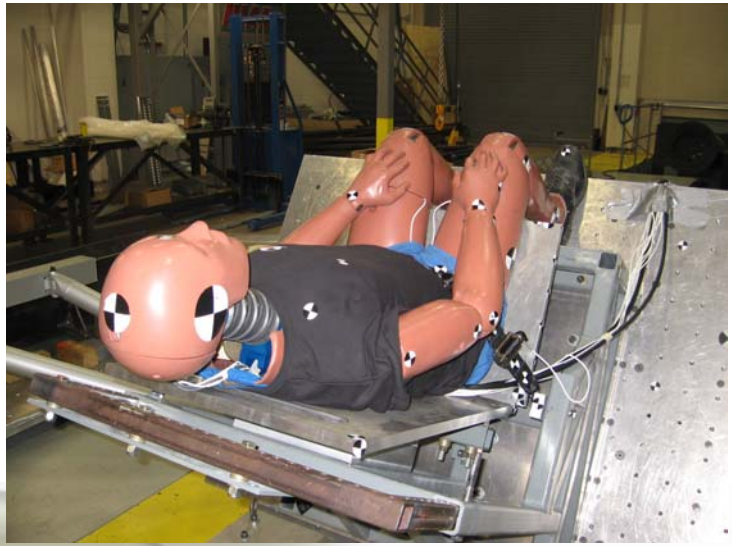
HIII FAA ATD Compliance Channels- FAR 25.562 – 60 deg

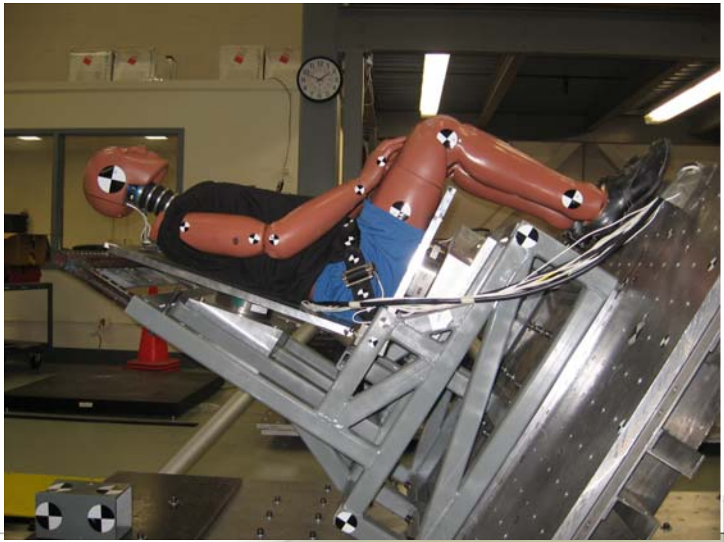


Validation Example: HIII FAA FAR 25.562

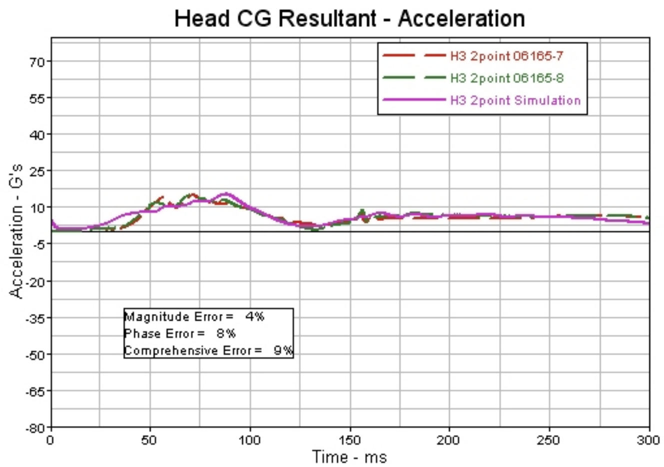


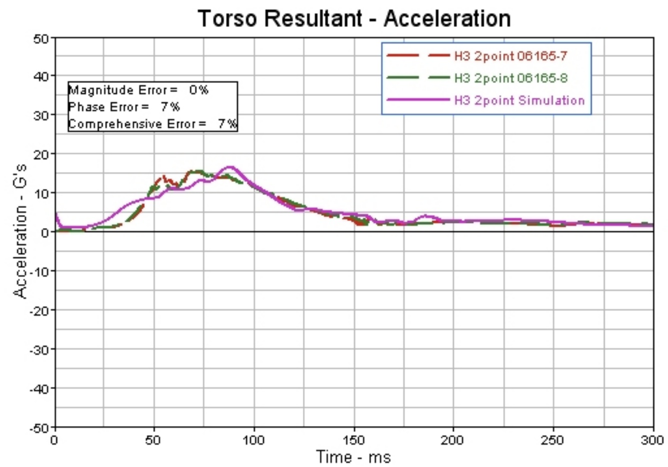


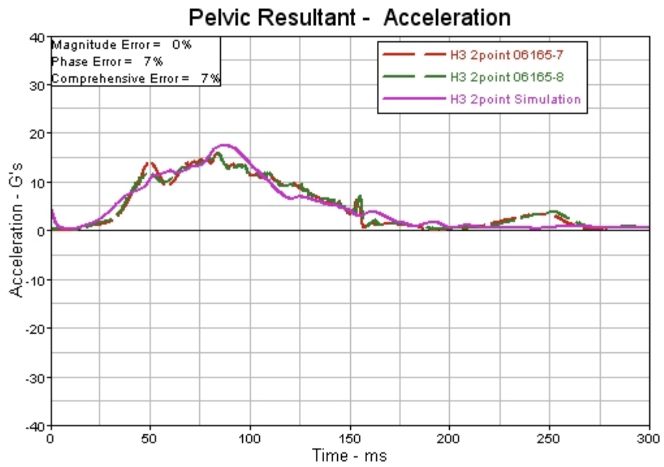


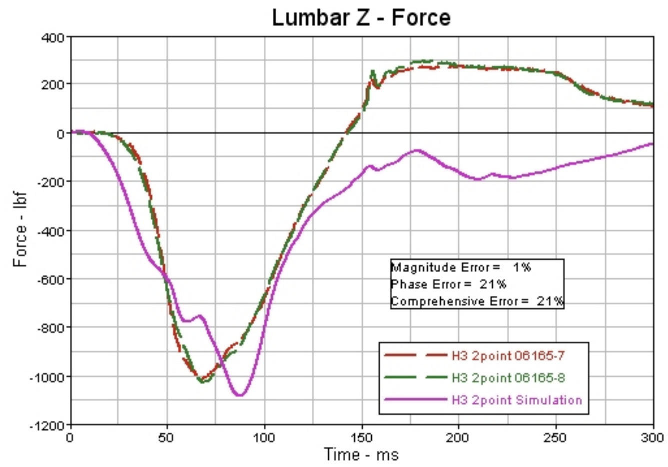


Validation Example I: Sample Responses

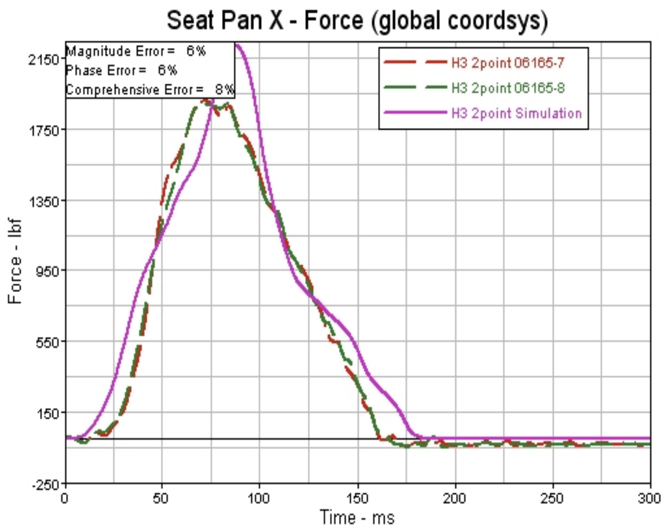


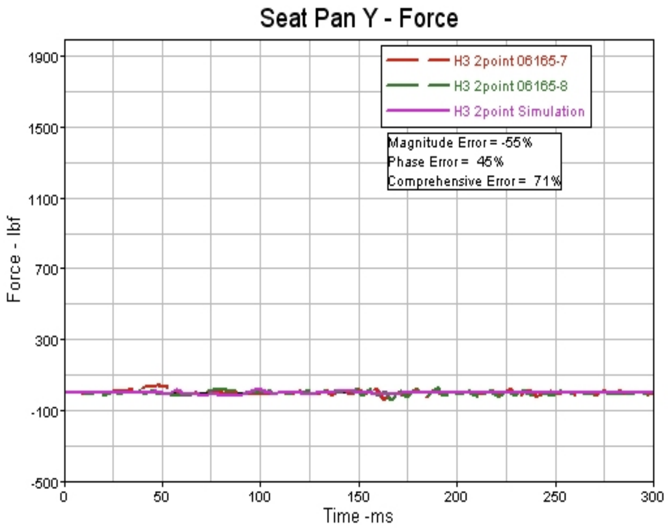


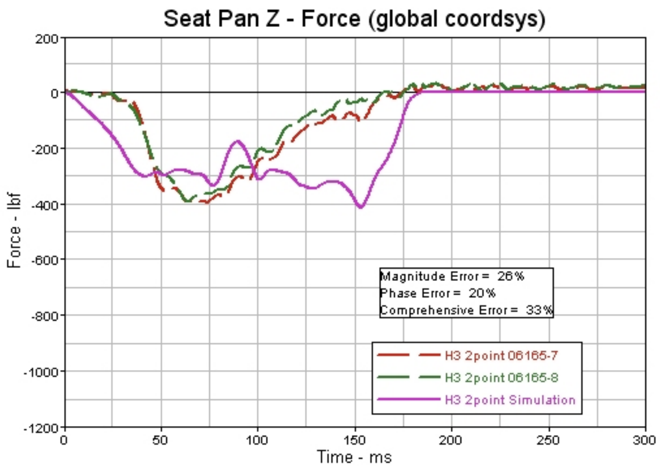


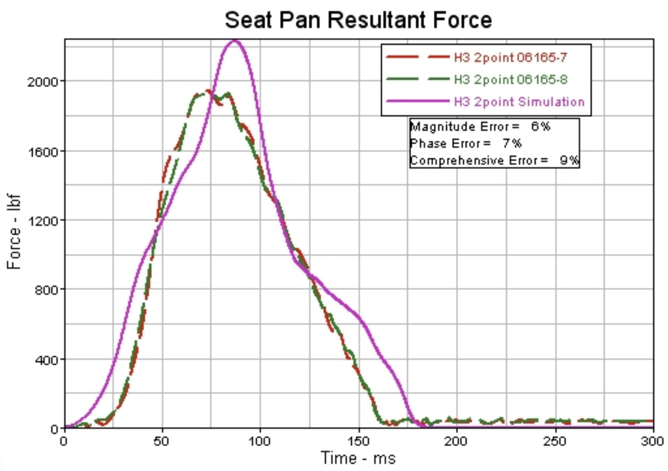


Validation Example I: Sample Responses





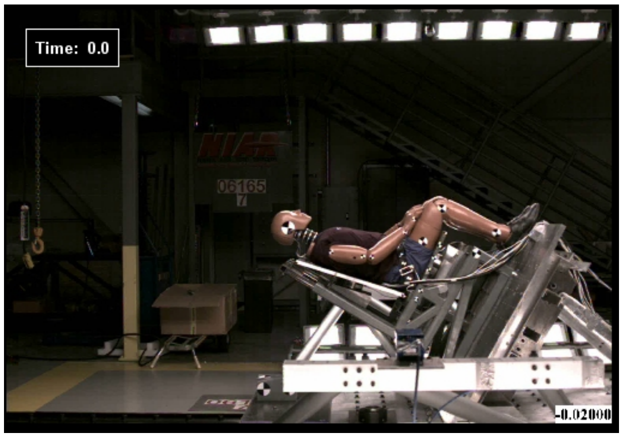


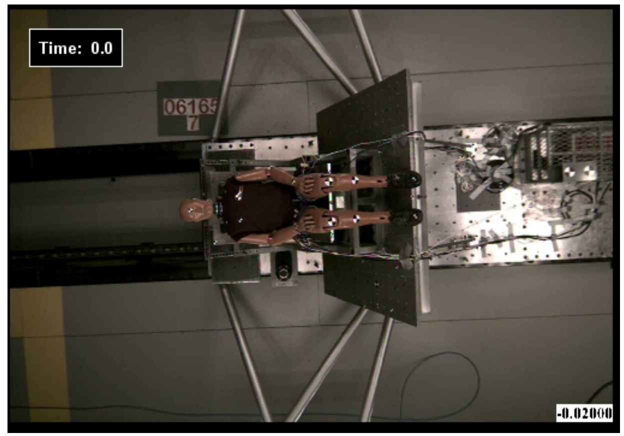


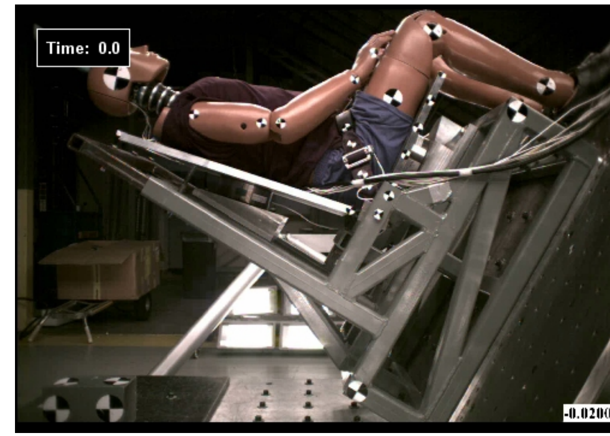
Validation Example I: Validation Metric (S&G)

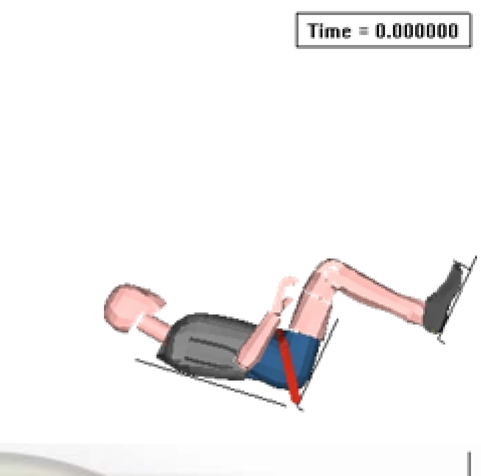
CHANNEL	TEST CONDITION		MAGNITUDE ERROR	PHASE ERROR	COMBINED
HEAD RESULTANT ACCELERATION	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	5%	4%	6%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	4%	8%	9%
SEAT PAN REACTION FORCE X	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	5%	2%	5%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	6%	6%	8%
SEAT PAN REACTION FORCE Y	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	-5%	22%	22%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	-55%	45%	71%
SEAT PAN REACTION FORCE Z	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	-1.35%	1.01%	1.69%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	26%	20%	33%
SEAT PAN REACTION FORCE RESULTANT	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	-0.90%	1.00%	1.34%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	6%	7%	9%
LAP BELT REACTION FORCE LEFT	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	5%	2%	6%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	118%	22%	120%
LUMBAR LOAD	TEST vs. TEST	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 60° (06165-8)	0.55%	1.27%	1.38%
	TEST vs. Simulation	2 POINT BELT, 60° (06165-7) 2 POINT BELT, 0° (SIMULATION)	1%	21%	21%

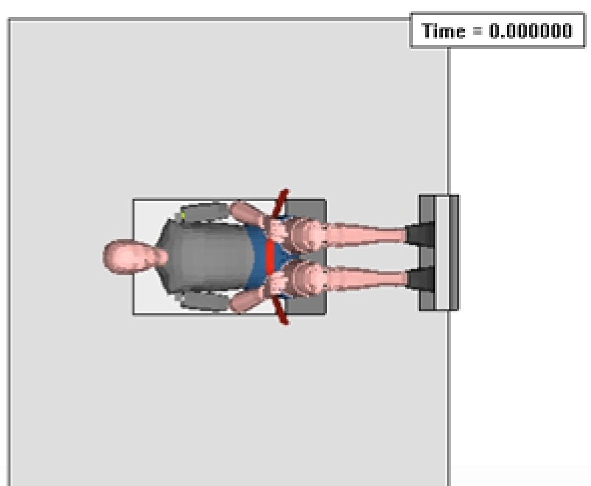
Validation Example I: Occupant Kinematics

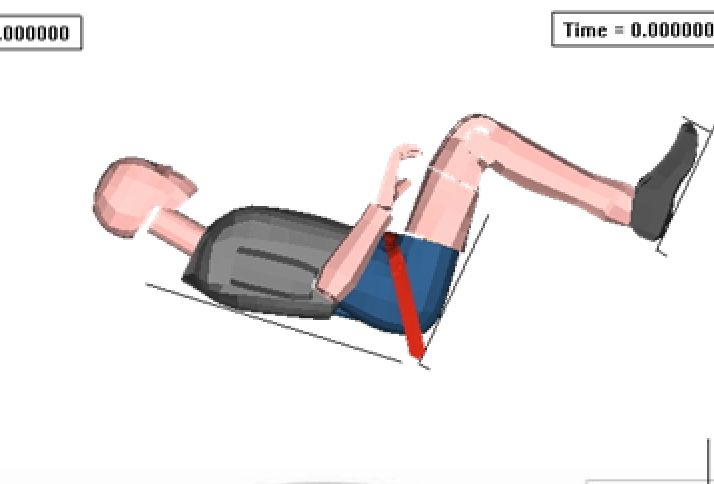




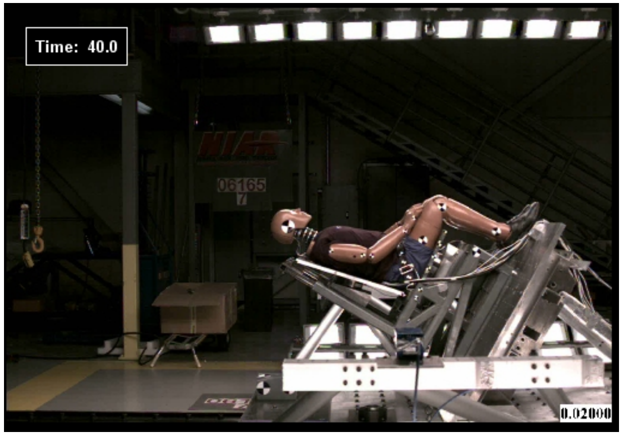


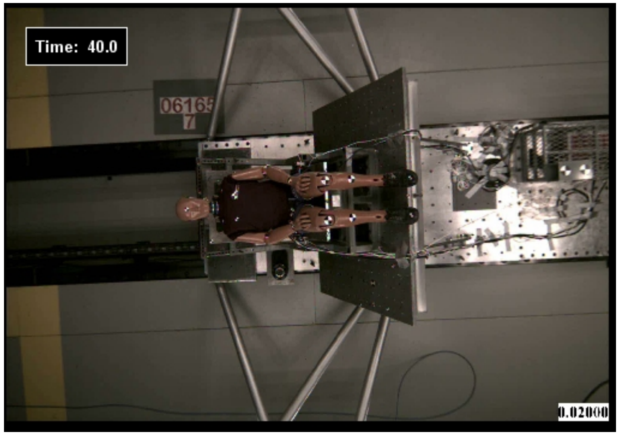


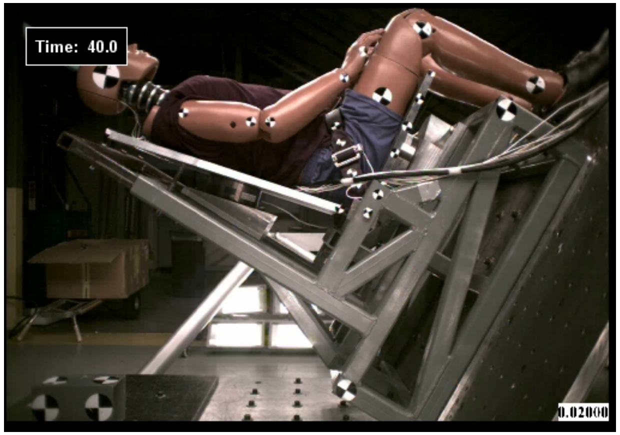


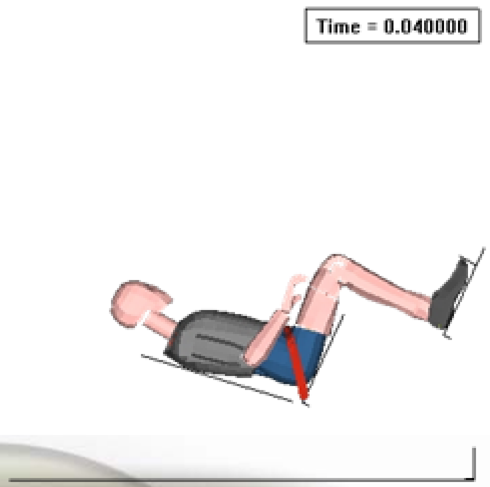


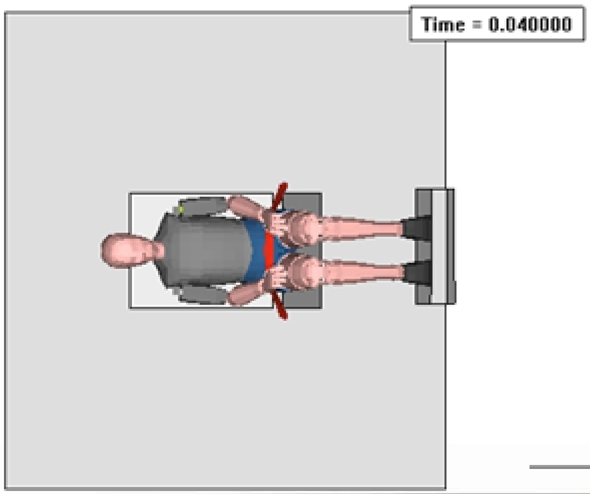
Validation Example I: Occupant Kinematics

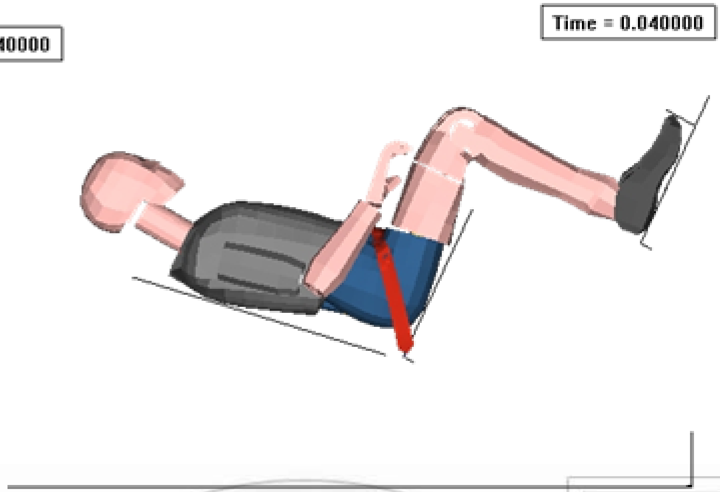




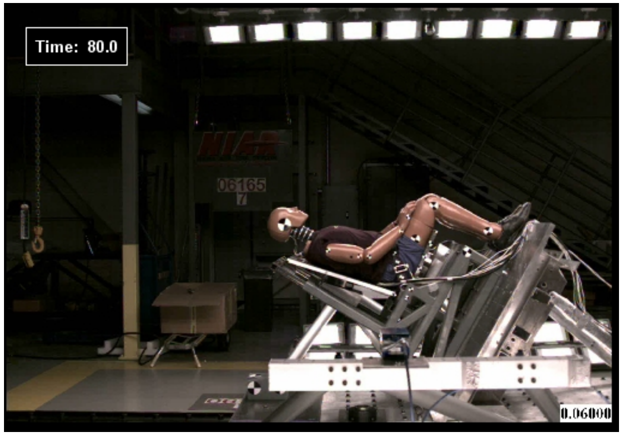


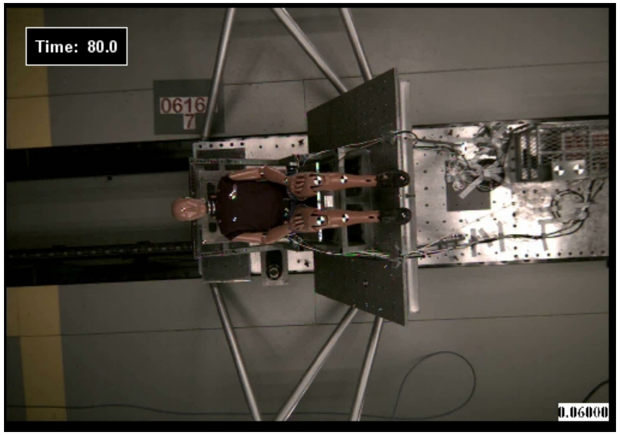


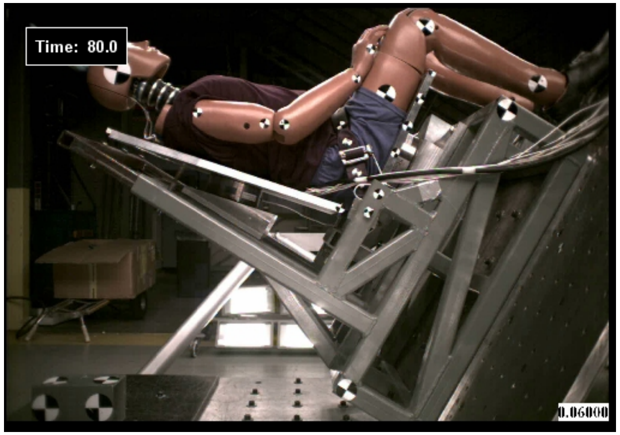


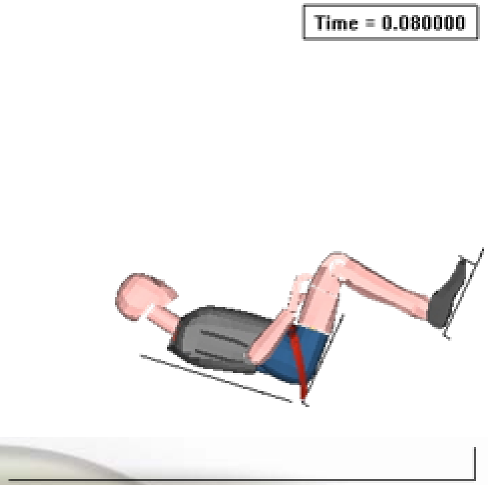


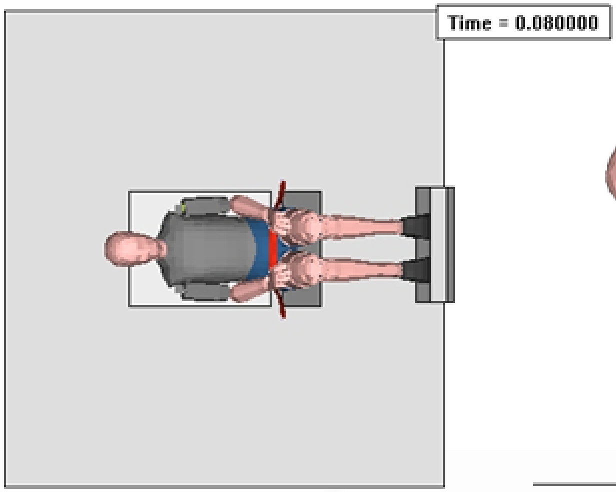
Validation Example I: Occupant Kinematics

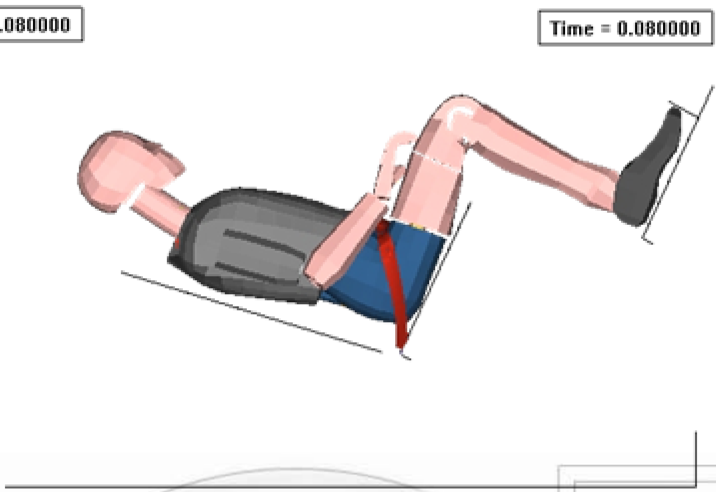




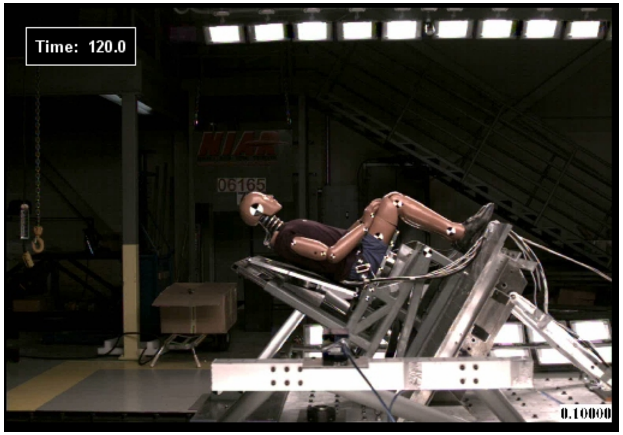


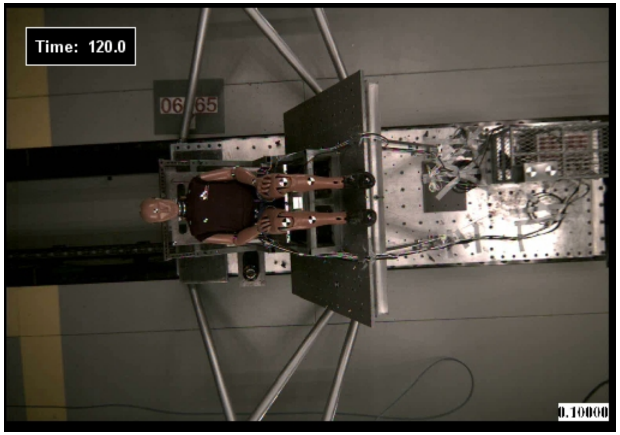


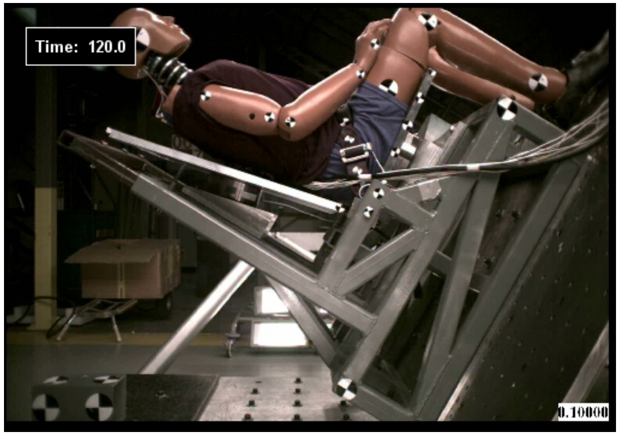


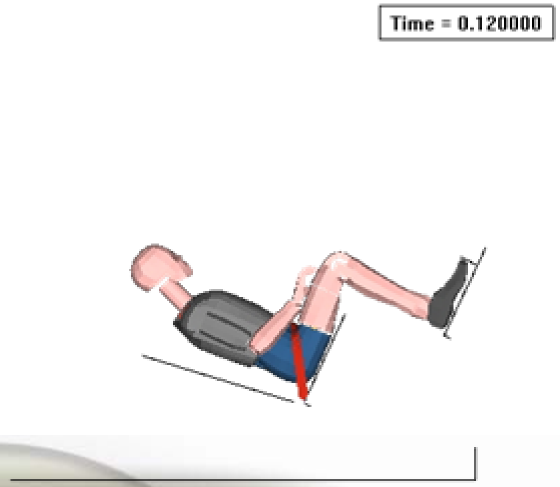


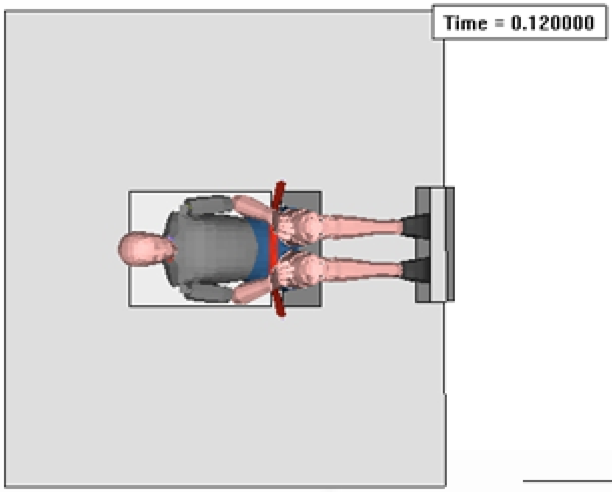
Validation Example I: Occupant Kinematics

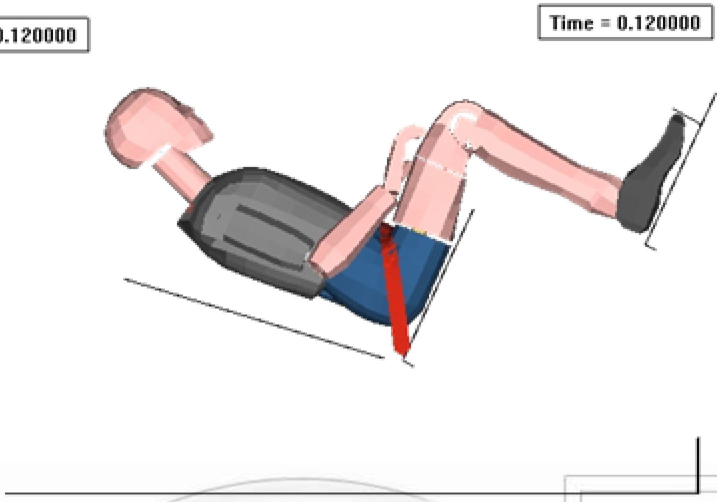




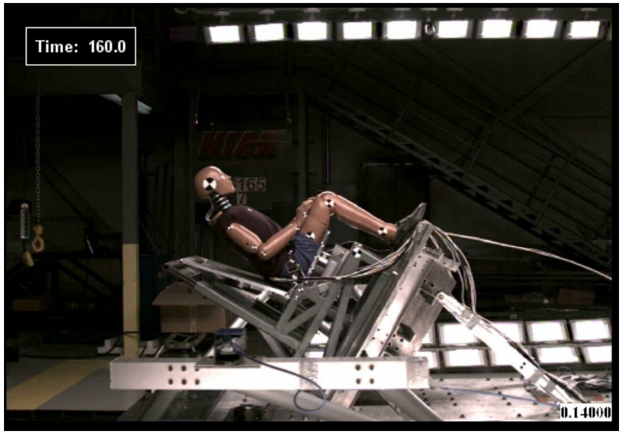


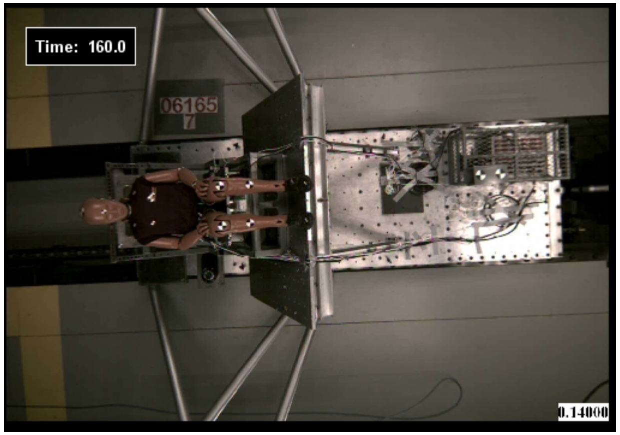


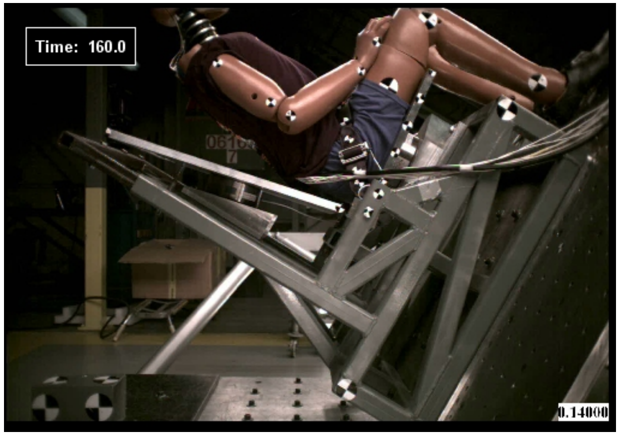


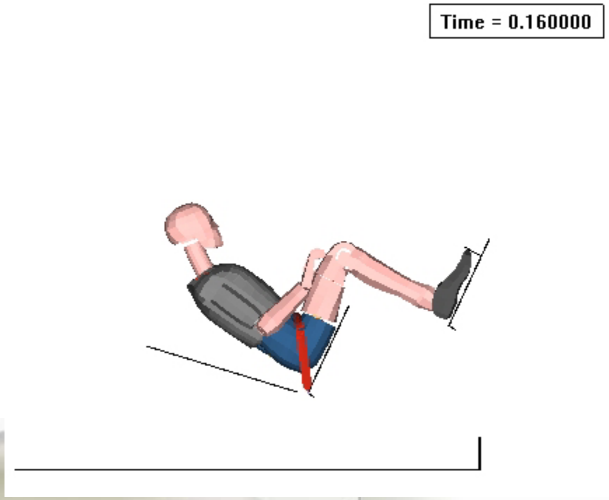


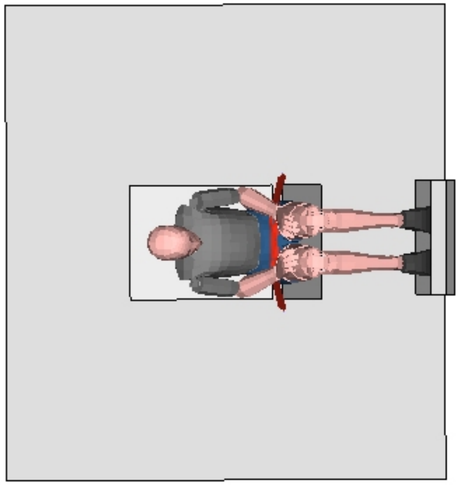
Validation Example I: Occupant Kinematics

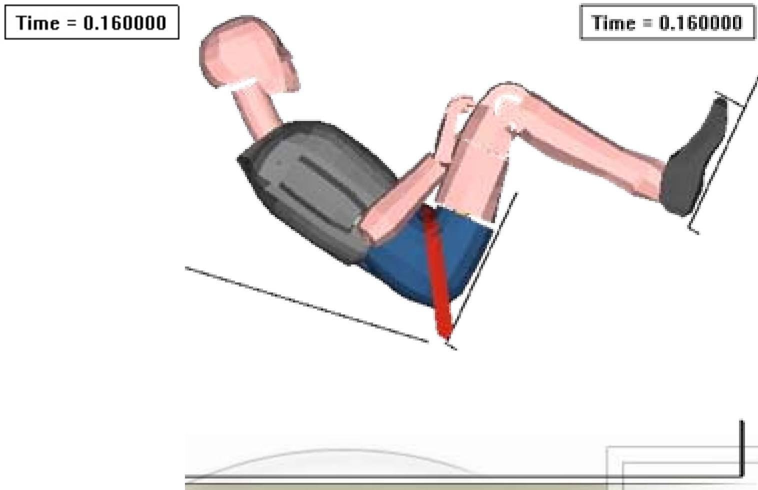




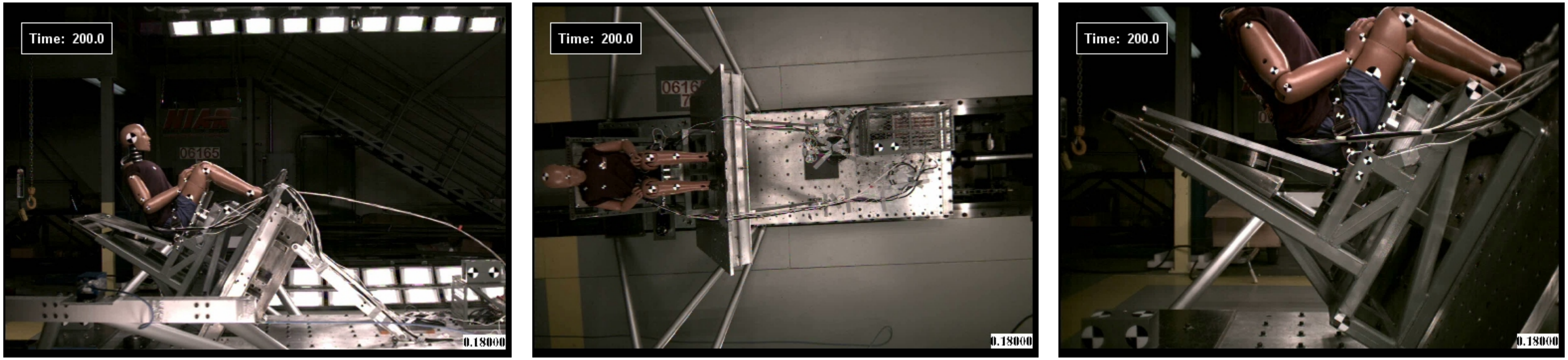


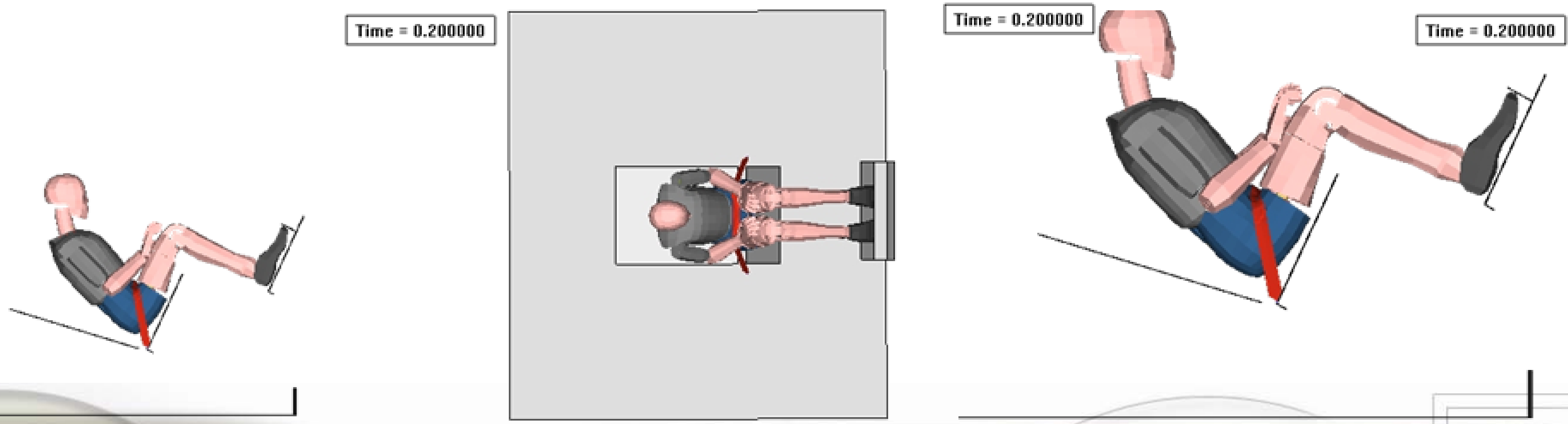




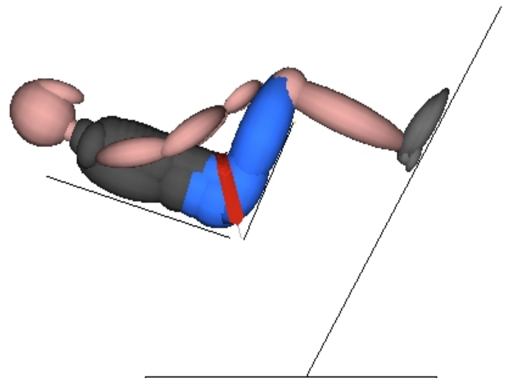


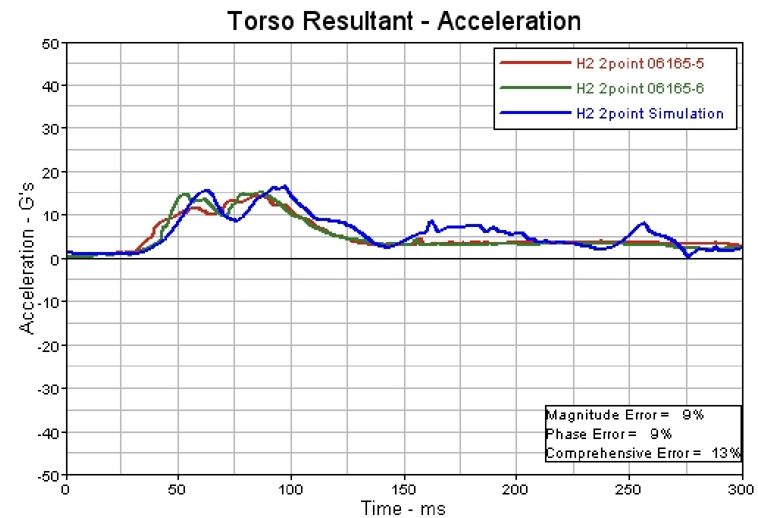
Validation Example I: Occupant Kinematics

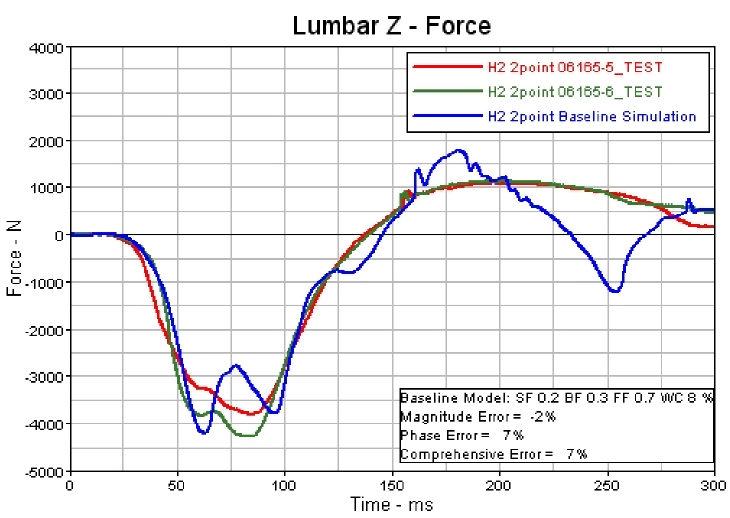


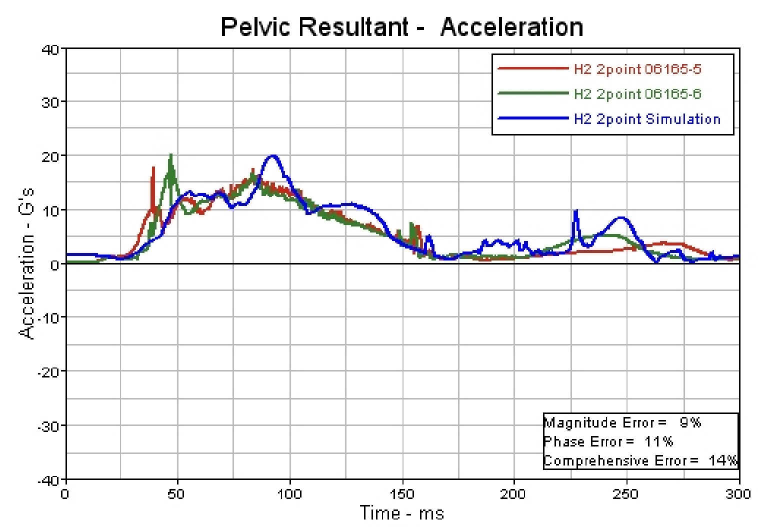


Validation Example II: Sample Responses



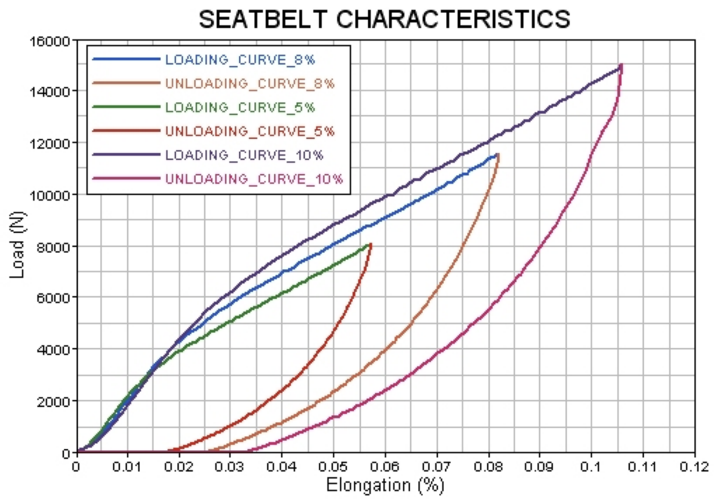




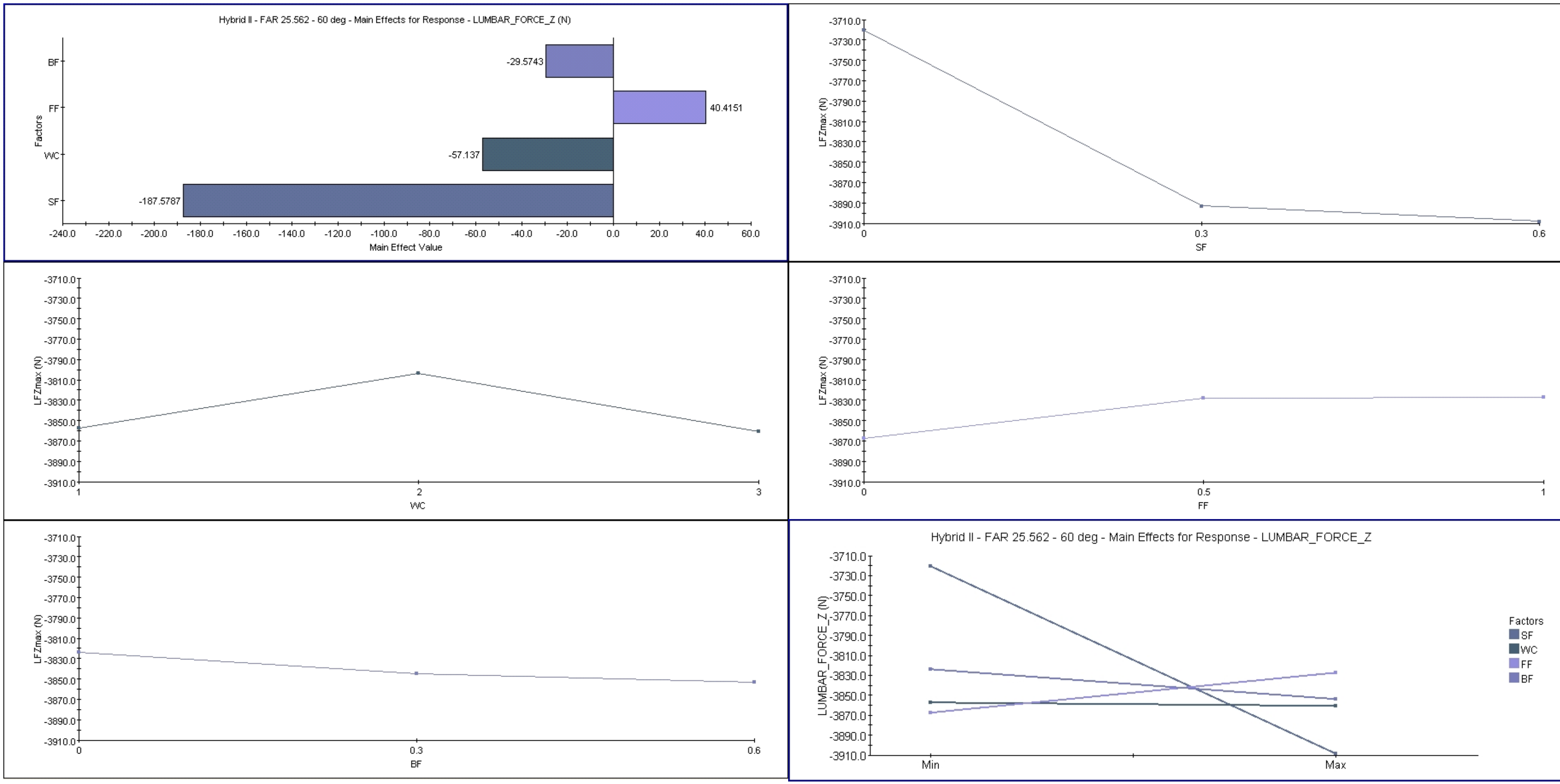


Validation Example II: Model Sensitivity Study

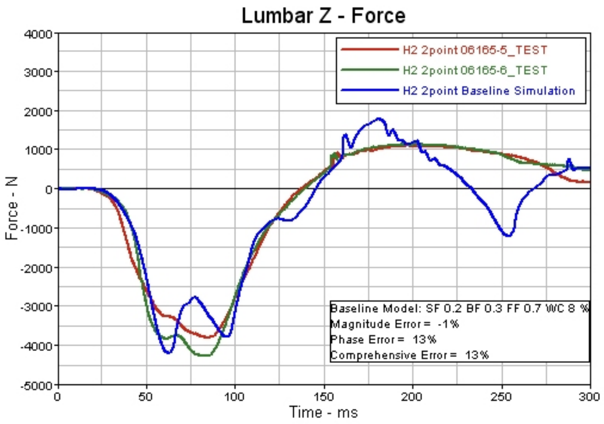
- Study the effect of modeling parameters:
  - Webbing Characteristics: 5 % / 8 % / 10%
  - Seat/ATD Friction: 0 / 0.3 / 0.6
  - Belt/ATD Friction: 0 / 0.3 / 0.6
  - Feet ATD/Ground Plane: 0 / 0.5 / 1.0
- Design of Experiment Setup:
  - Number of Discrete Factors: 4
  - Number of Responses: 25
  - Total Runs: 81
  - Model Complexity: Least Square
  - Model Resolution: Quadratic
  - Number of Terms: 33
  - DOE Type: Full Factorial (Mixed Levels)

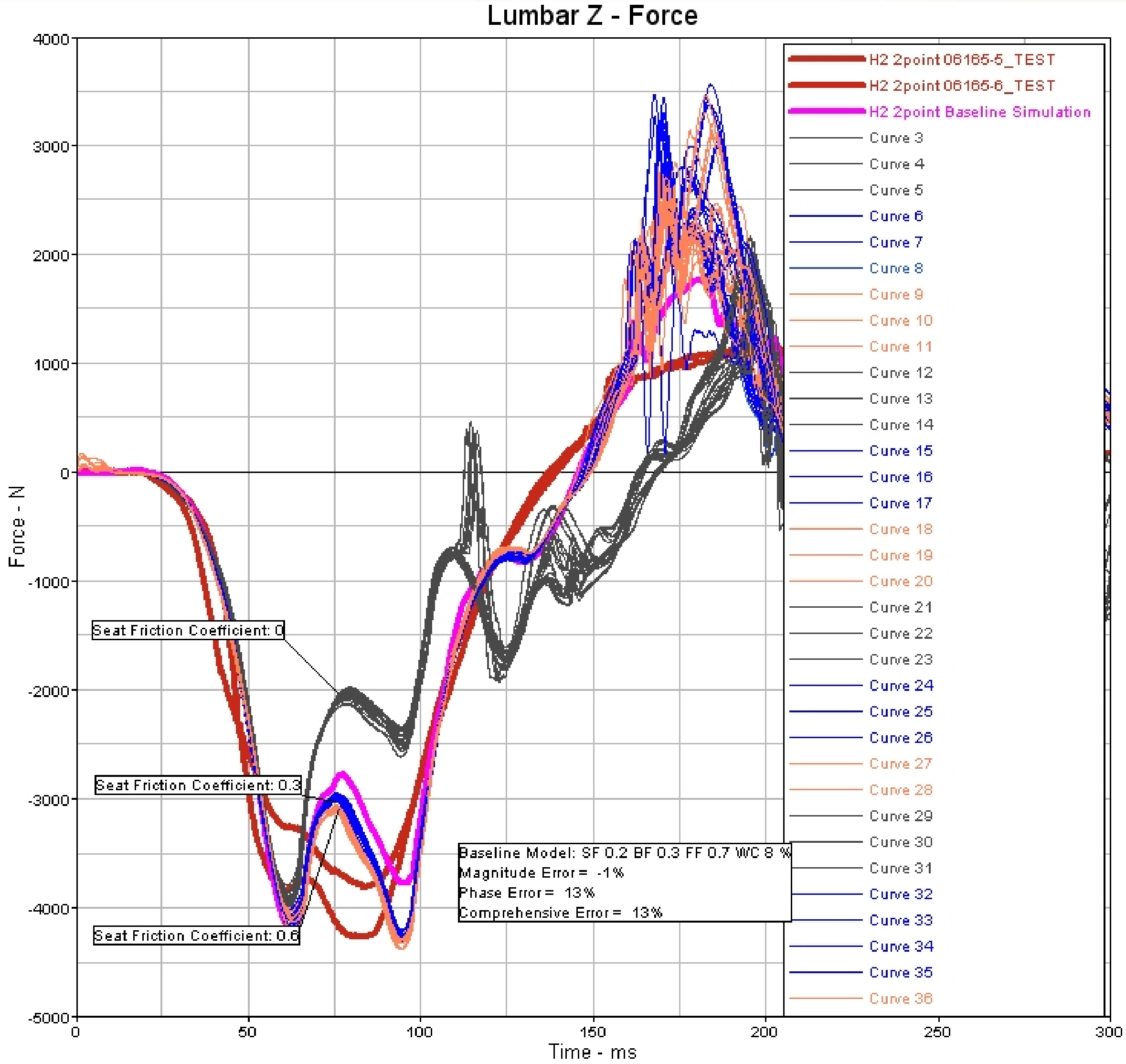


Val. Example II: Sample Lumbar Load Sensitivity

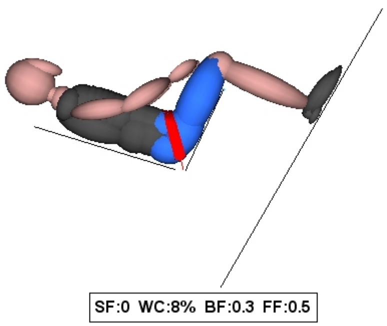


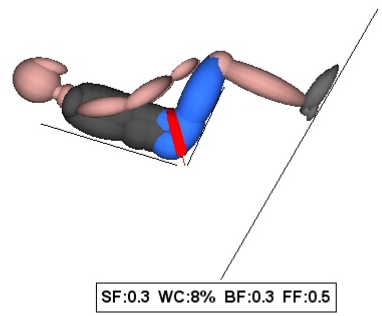
Val. Example II: Sample Lumbar Load Sensitivity

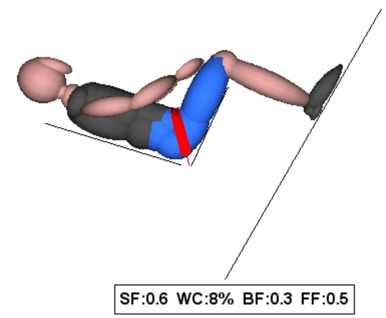


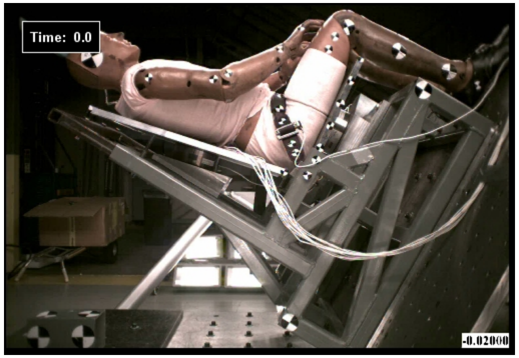


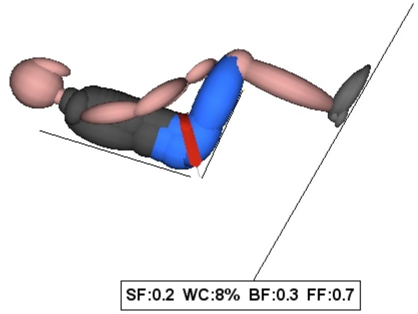
Validation Example II: Occupant Kinematics

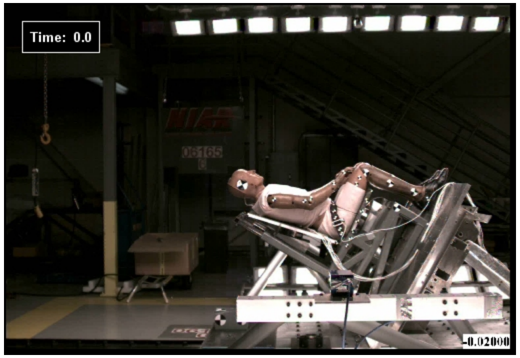




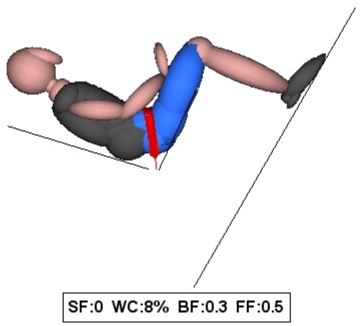


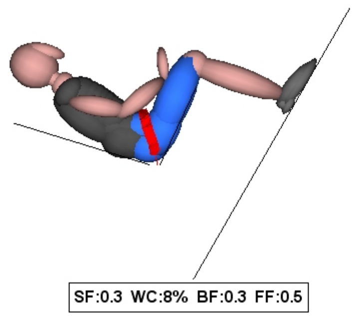


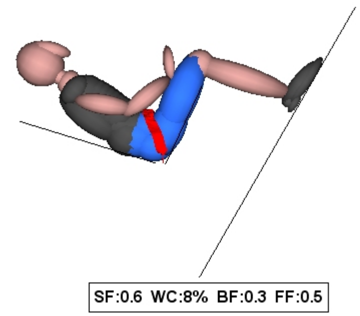


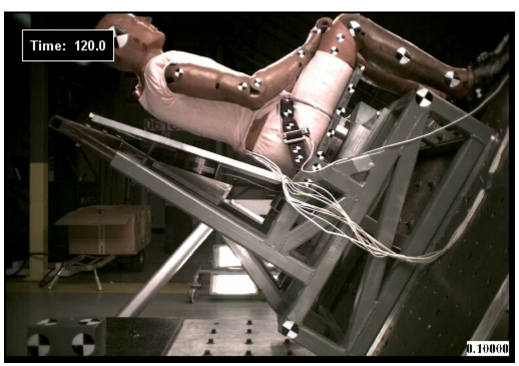


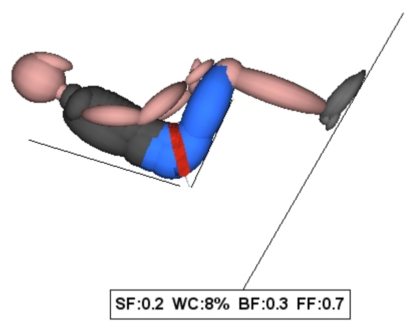
Validation Example II: Occupant Kinematics

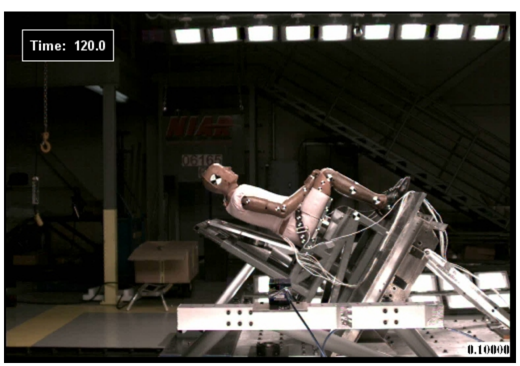












Conclusion

- 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