Crashworthiness Certification by Analysis: Numerical Model Preparation and Analysis Guidelines

Gerardo Olivares

A Center of Excellence AMTAS Advanced Materials in Transport Aircraft Structures

WICHITA STATE UNIVERSITY

CECAM Center of excellence for composites and advanced materials

The Joint Advanced Materials and Structures Center of Excellence

Certification by Analysis

- Motivation and Key Issues
  - Physical testing certification costs and long product development cycles.
- Objective
  - Provide an overview of best practices so that Industry and ACOs can gain an understanding of the fundamental modeling methods, a feeling for the comparative usefulness of different numerical approaches, develop an appreciation of the modeling problem areas, and limitations of current numerical models.
- Approach
  - Three Phases: Review, Application Case I, and Application Case II

FAA Sponsored Project Information

- Principal Investigators & Researchers
  - Gerardo Olivares, PI
- FAA Technical Monitor
  - Allan Abramowitz
- Other FAA Personnel Involved
  - Rick Dewesse (CAMI)
  - David Moorcroft (CAMI)
- Industry Participation
  - B/E Aerospace, Schroth Safety Products, TASS-TNO, Cessna, Raytheon

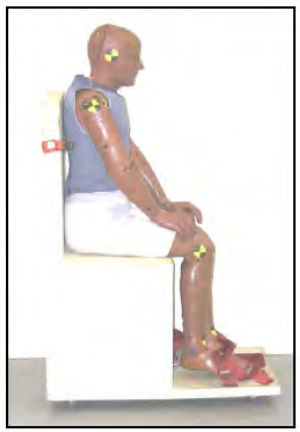
AC 20-146 - Scope

- 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 – Solvers and Occupant Models

- The following combination of computer codes and occupant models have been used in support of the design and certification of dynamic seats. This is not an exhaustive list. Codes not identified here, but shown to be equivalent to those referenced below, may be utilized as well:
  - **MADYMO** transient finite element/multi-body software and the MADYMO 50 percent part 572 Subpart B Hybrid II occupant model. [MADYMO is a registered trademark of TNO Road-Vehicles Research Institute.]
  - **MSC/DYTRAN** transient finite element software and the ATB Hybrid II occupant model. [MSC/DYTRAN is a registered trademark of the MacNeal –Schwendler Corporation. ATB is a public domain code developed and maintained by Wright Patterson Air Force Base.]
  - **LS-DYNA3D** transient finite element software and the MADYMO 50 percent part 572 Subpart B Hybrid II occupant model. [LS-DYNA3D is a registered trademark of the Livermore Software Technology Corporation.] LS-DYNA3D may also be similarly interfaced with the Air Force developed ATB software. A finite element representation of the ATD is a third modeling alternative.

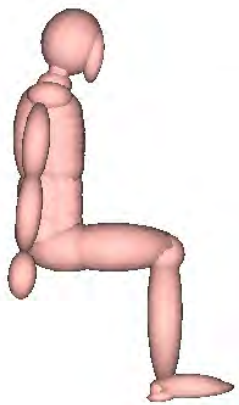
ATD Databases - MADYMO

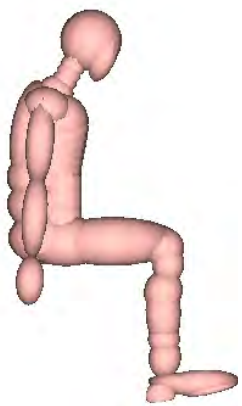


Standard
Hybrid II

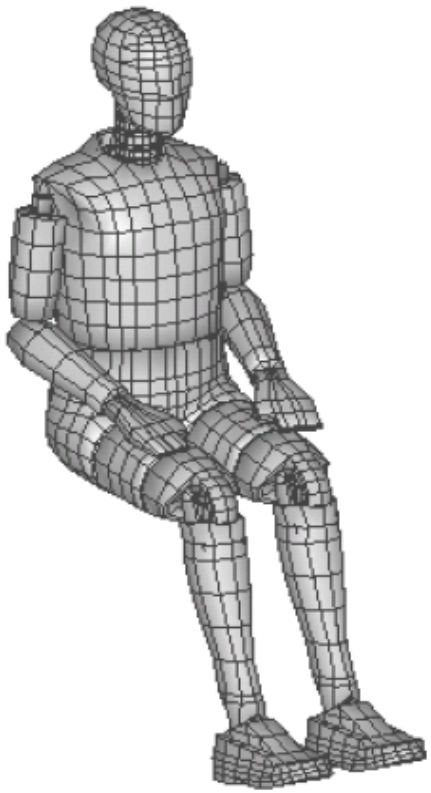
Standard
Hybrid III

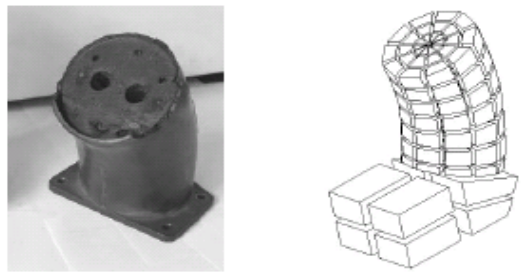
FAA
Hybrid III



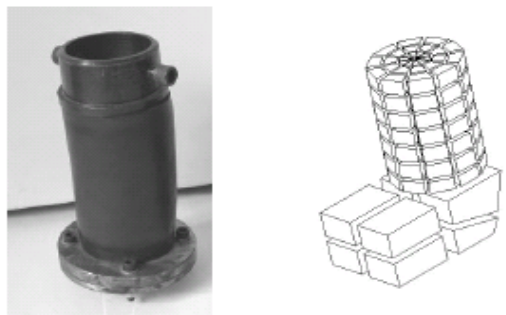


ATD Databases - LSDyna





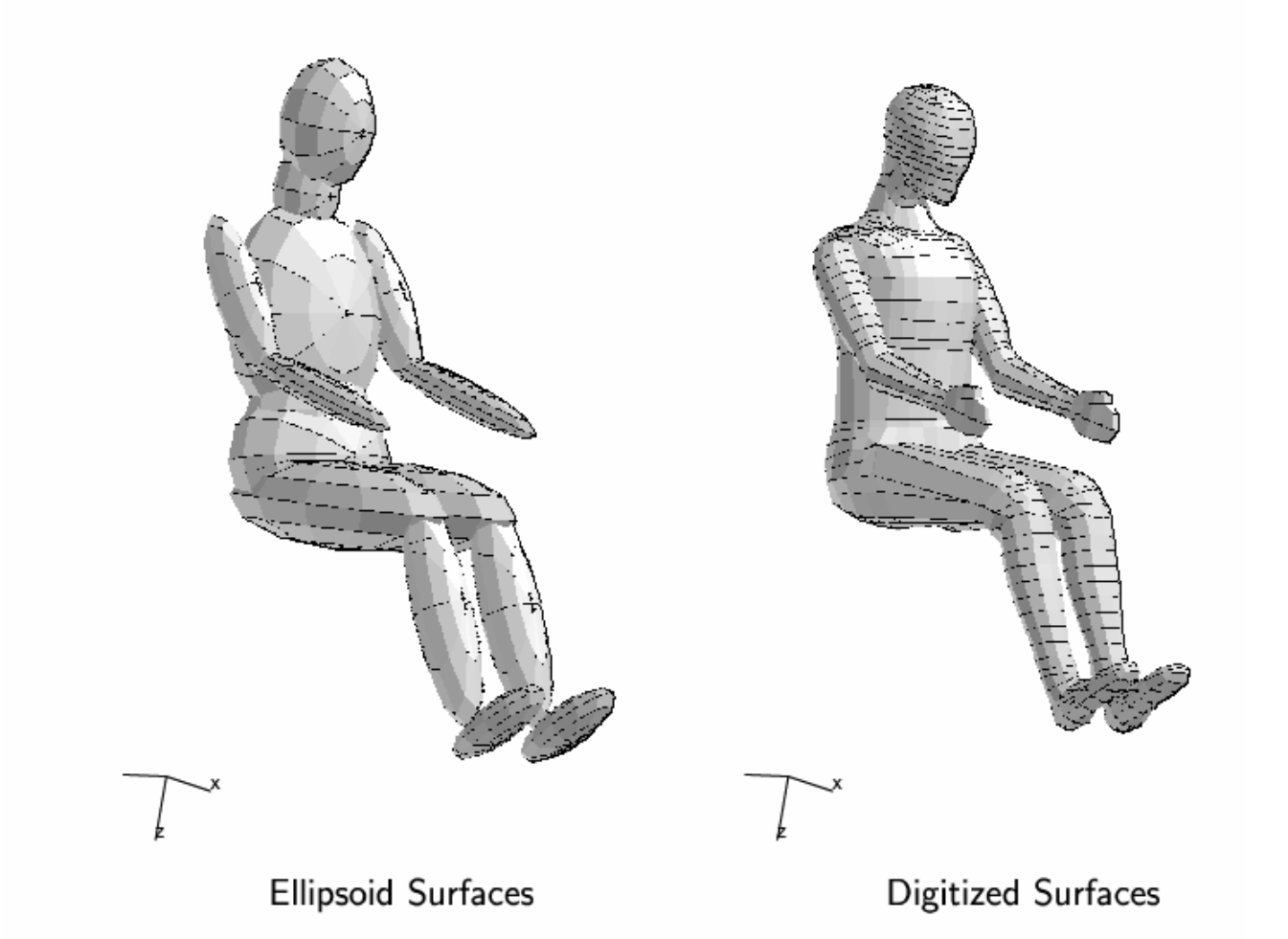
Automotive Hybrid III



Aeronautical Hybrid III

Note this model is **not public domain**. It belongs to Politecnico di Milano

ATD Databases - Hybrid II ATB



Problem Areas

- Joints and fittings:
  - Definitions
    - FE
    - MB
  - Failure models
  - Failure mechanisms
- Materials:
  - Strain rate input data
  - Tension / Compression data
  - Testing specifications
  - Material model definitions: foams, metals, etc.
- Restraint System Modeling:
  - Retractors
  - Webbing
  - Webbing properties

- Model validation procedures:
  - Sled test documentation procedure:
    - Pre and post measurements
    - Seat Instrumentations:
      - Strain gauges - locations
      - Load Cells
      - Targets
    - Belt System:
      - Webbing length
      - Payout
      - Retractor forces
      - Belt anchor forces
  - Numerical validation procedure
  - Quality check guidelines for numerical model

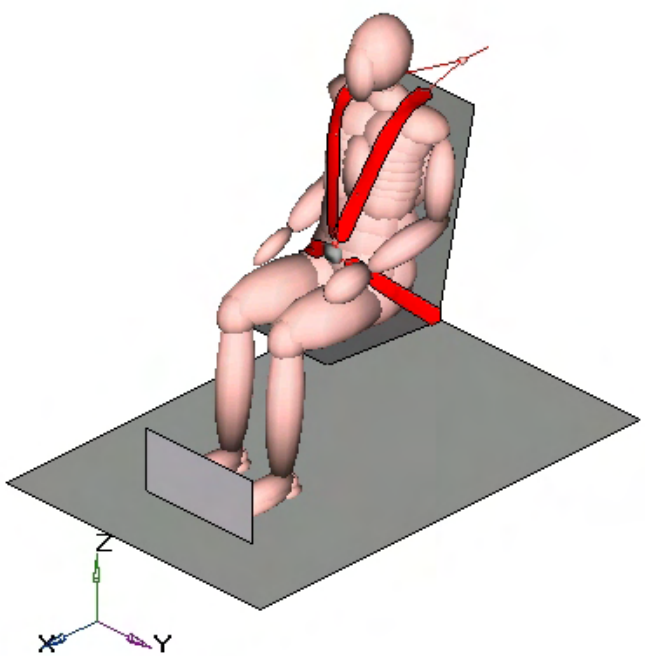
Sled Test Matrix

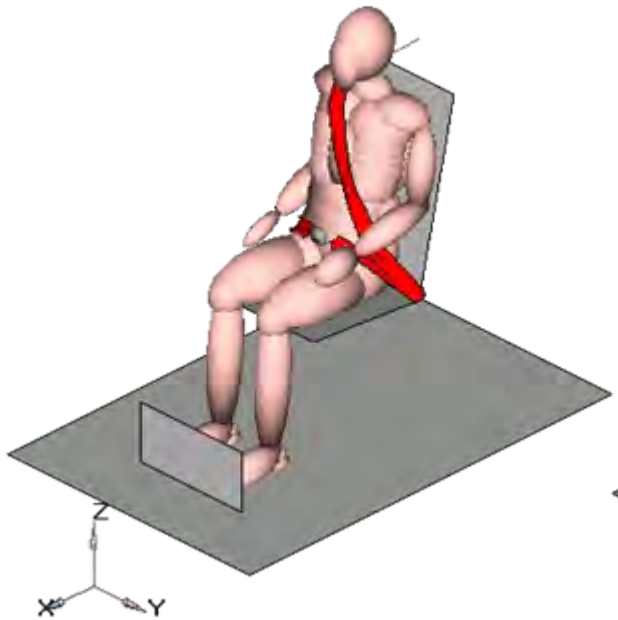
TEST CONFIGURATION	ATD	BELT TYPE	BELT MATERIAL	CRASH PULSE	TYPE	SEAT TYPE	# of Tests
1	HII	2	20 % Nylon	25.562	16 g	Rigid	2
2	HII	2	20 % Nylon	25.562	14 g - 60 deg	Rigid - Foam	2
3	HII	3	20 % Nylon	25.562	16 g	Rigid	2
4	HII	2	20 % Nylon	25.562	14 g - 60 deg	Rigid	2
5	HII	4	20 % Nylon	25.562	16 g	Rigid	2
6	HIII FAA	2	20 % Nylon	25.562	16 g	Rigid	2
7	HIII FAA	2	20 % Nylon	25.562	14 g - 60 deg	Rigid - Foam	2
8	HIII FAA	3	20 % Nylon	25.562	16 g	Rigid	2
9	HIII FAA	2	20 % Nylon	25.562	14 g - 60 deg	Rigid	2
10	HIII FAA	4	20 % Nylon	25.562	16 g	Rigid	2
							20

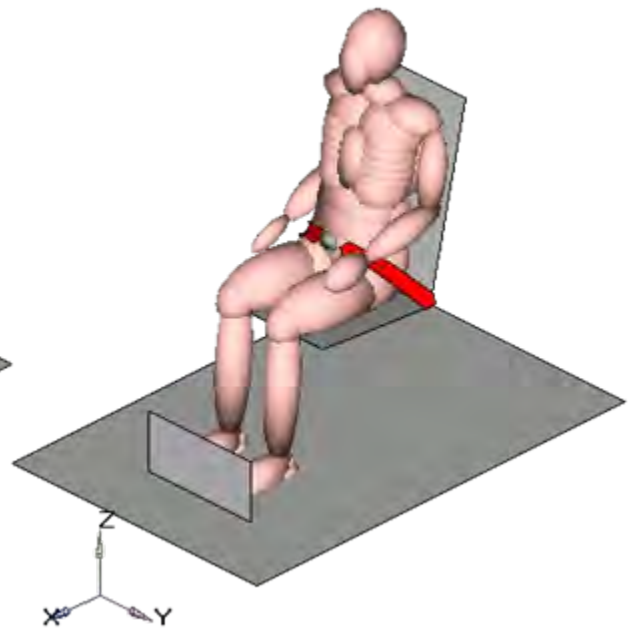
	June
	August

	Units	
2 Point Restraints	12	20 % Nylon or Similar
3 Point Restraints	4	20 % Nylon or Similar
4 Point Restraints	4	20 % Nylon or Similar
Cushion Foam	4	Typical FAR Part 25 Foam

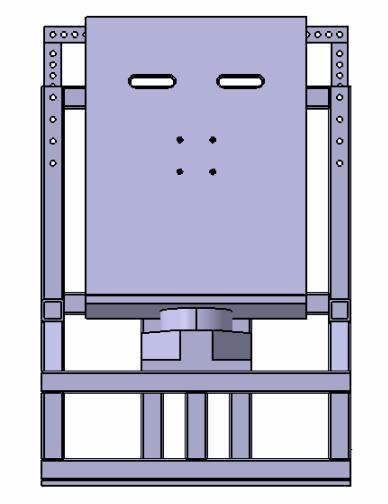
Belt Configurations

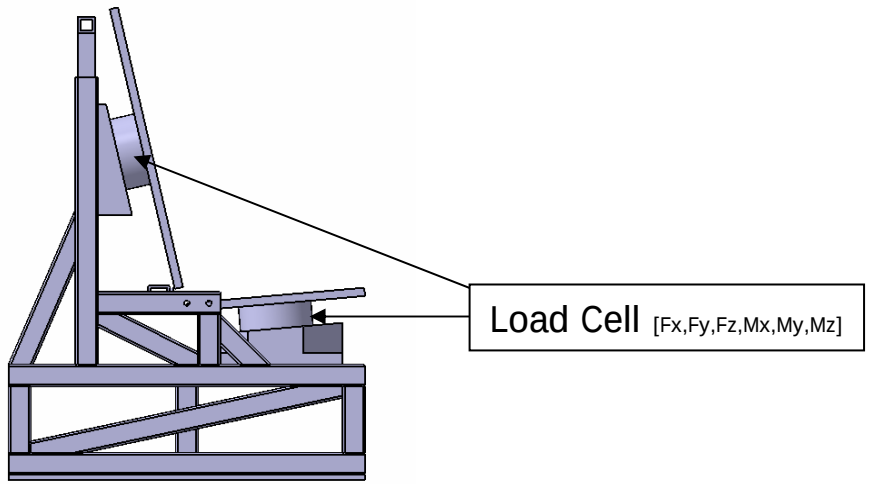


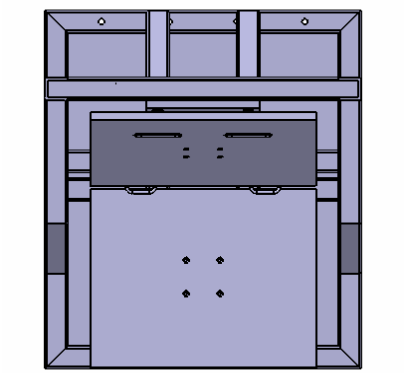


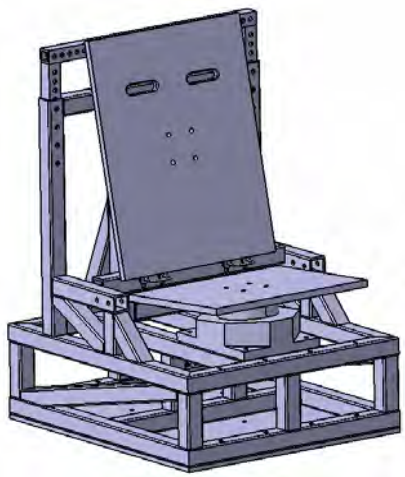


Rigid Seat Design









Rigid Seat Design

Restraint Configurations:
2 - Point
3 - Point
4 - Point
5 - Point

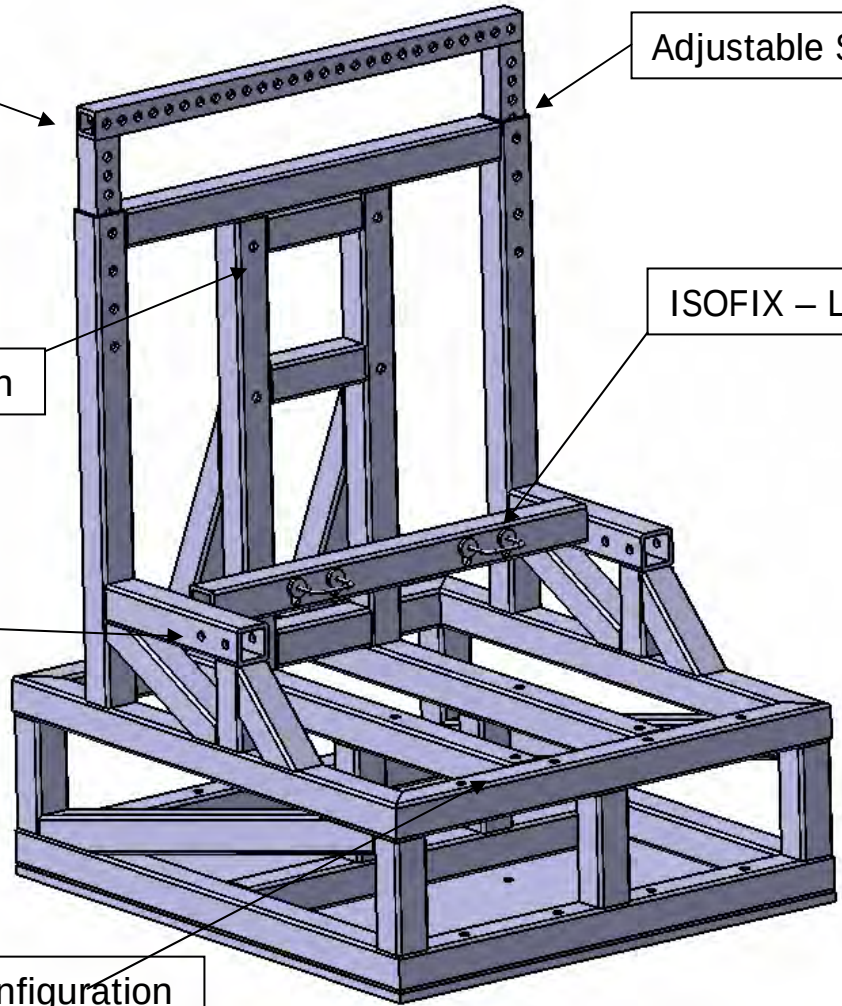
Adjustable Shoulder Harness Height

ISOFIX – Latch CRS Attachments

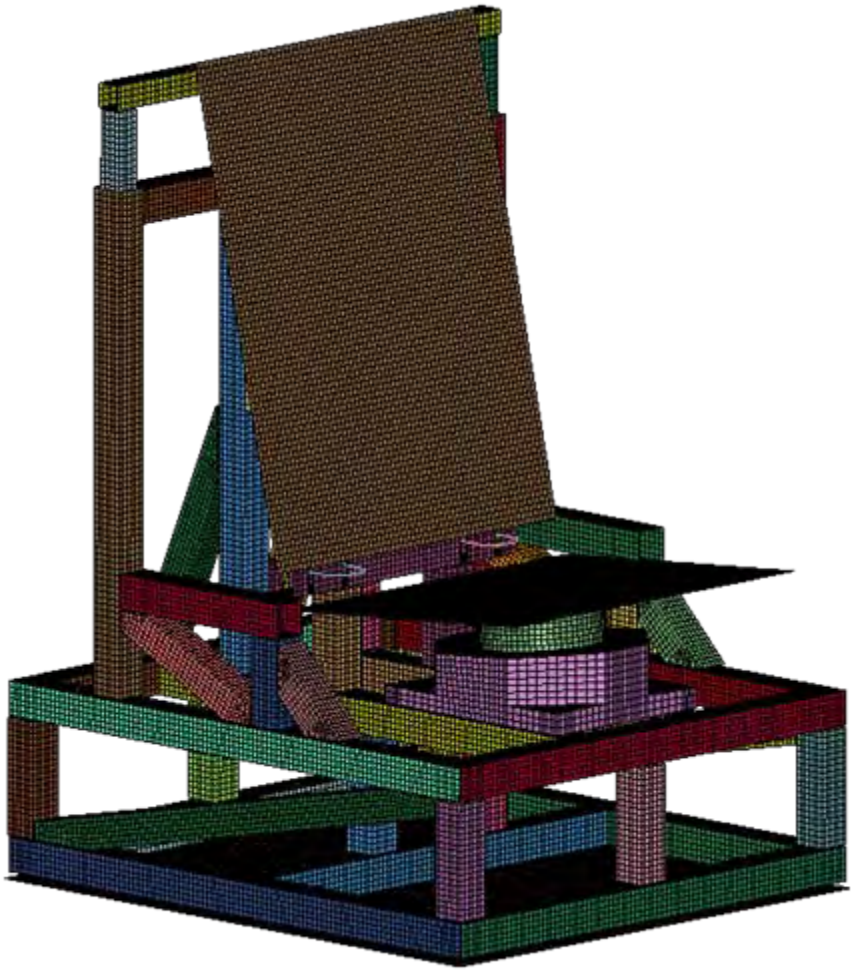
Adjustable Seat Back Configuration

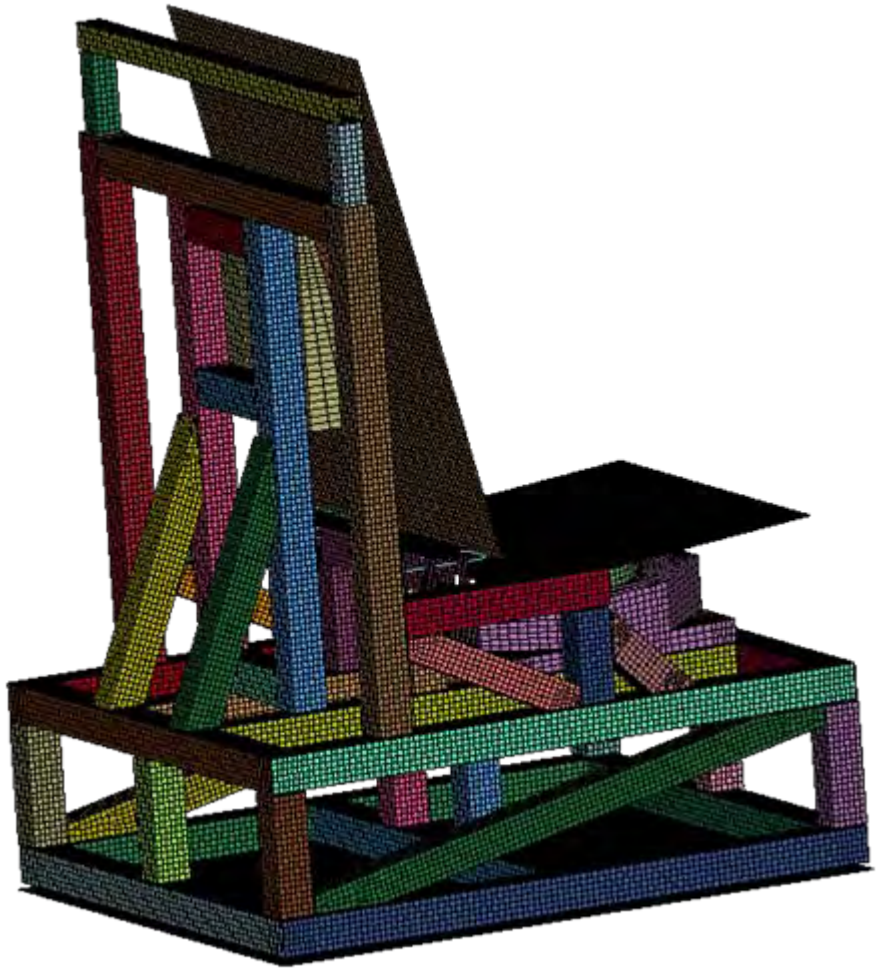
Adjustable Lap Belt

Adjustable Seat Pan Configuration



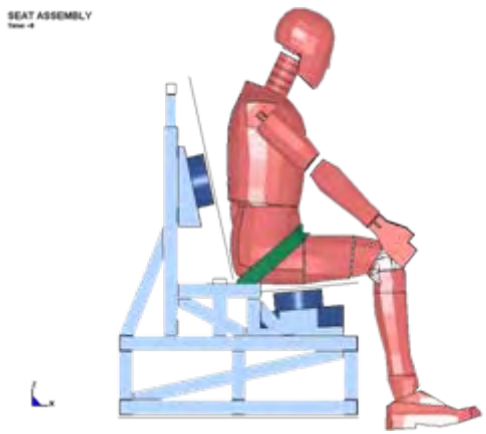
Rigid Seat FE Model





FAR 25.562 - ATD Kinematics

Time : 0s



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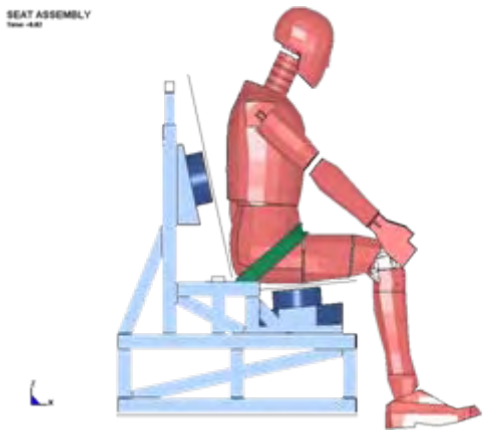

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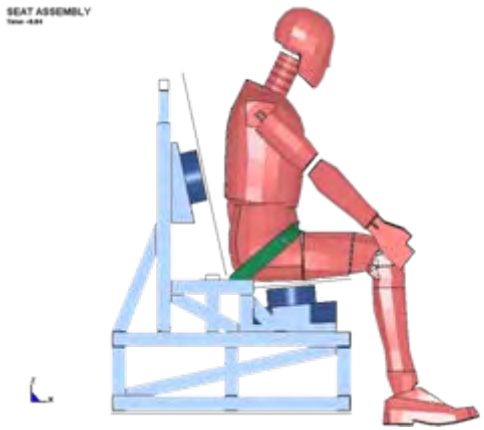

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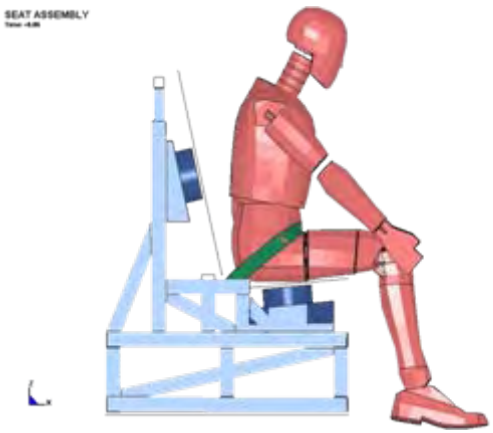

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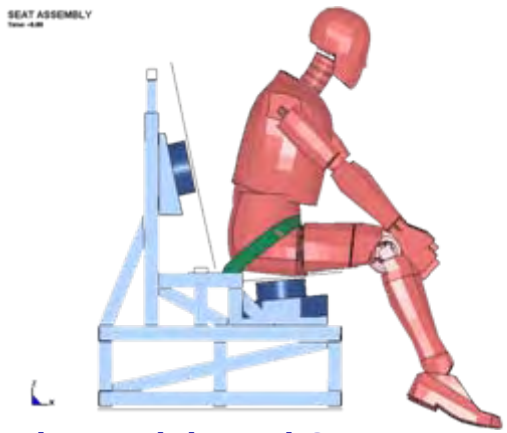

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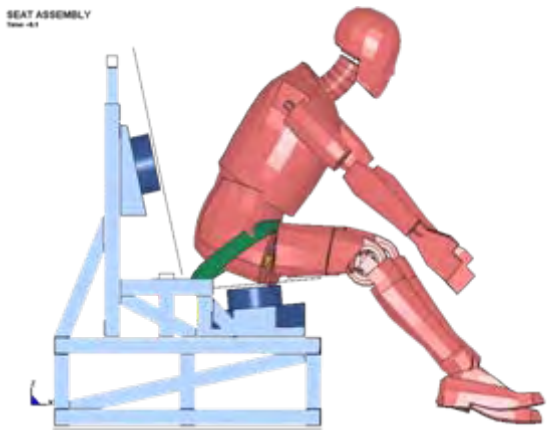
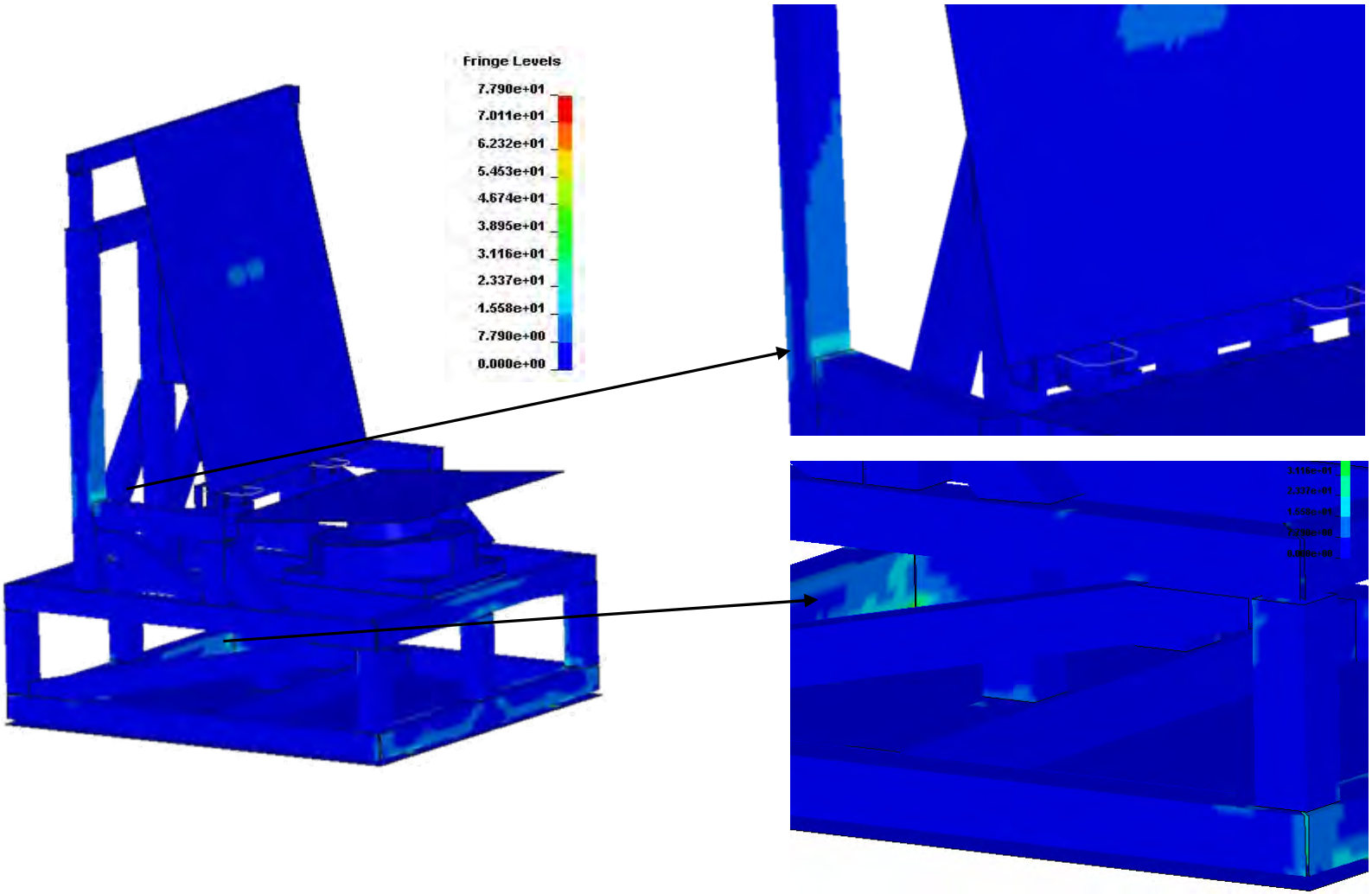
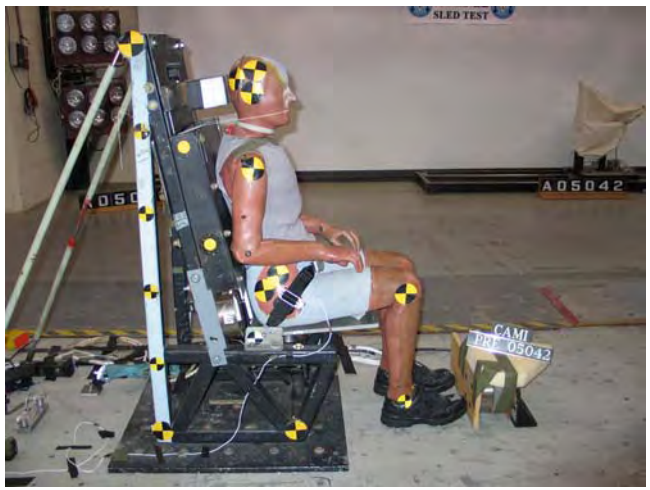
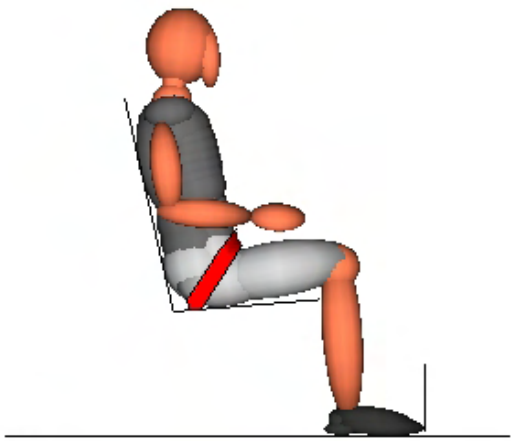


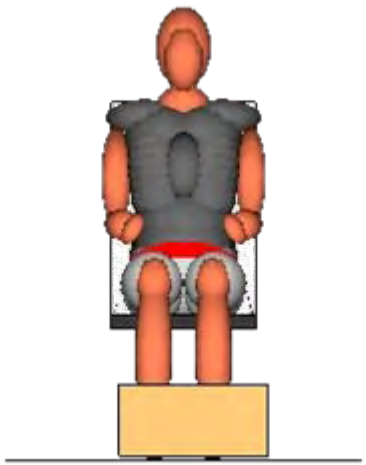
FAR 25.562 – von Mises Stress Contour (MPa)



Example I: 16 g Sled Test

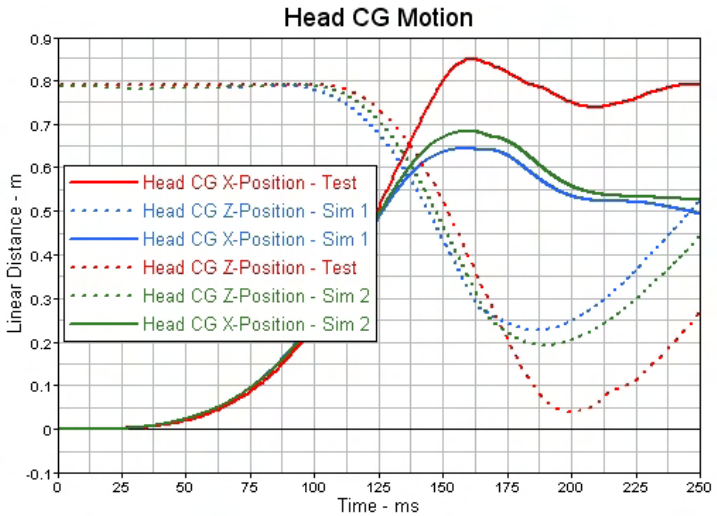


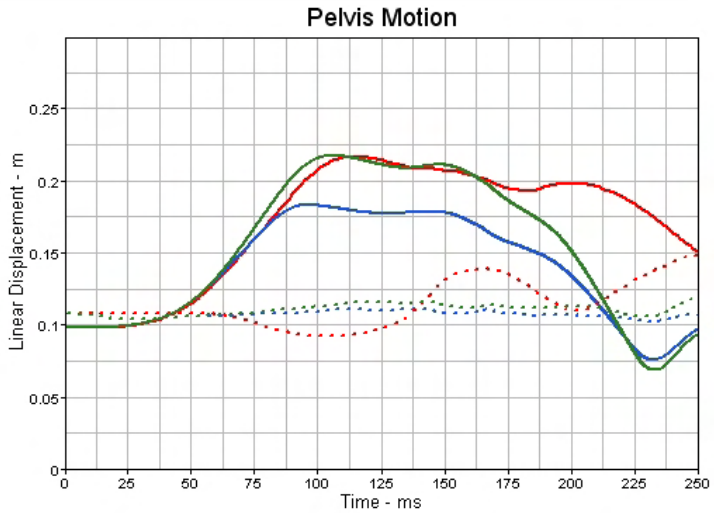


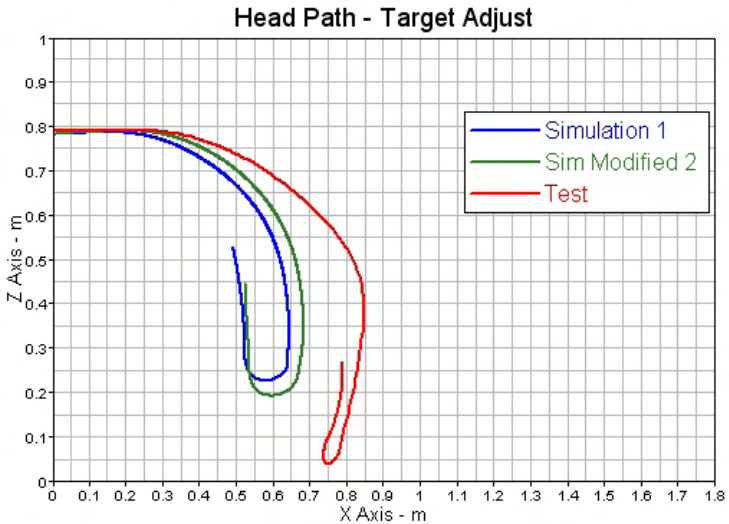


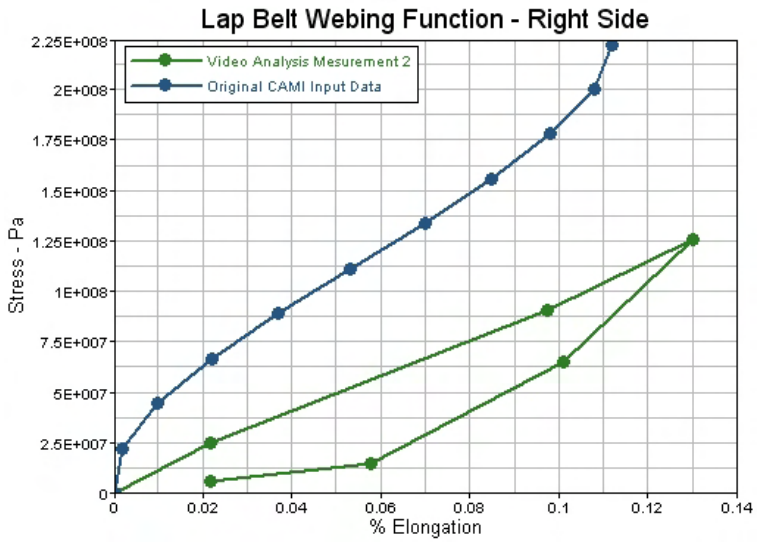
- 16g horizontal sled test with a Hybrid II 50th percentile dummy in a rigid seat with a standard aviation passenger lap-belt and a foot-stop. There is no seat cushion. The seat pan is approximately 5° from horizontal and the seat back is approximately 13° from vertical.
- CAMI Test 05042

Example I: Displacement

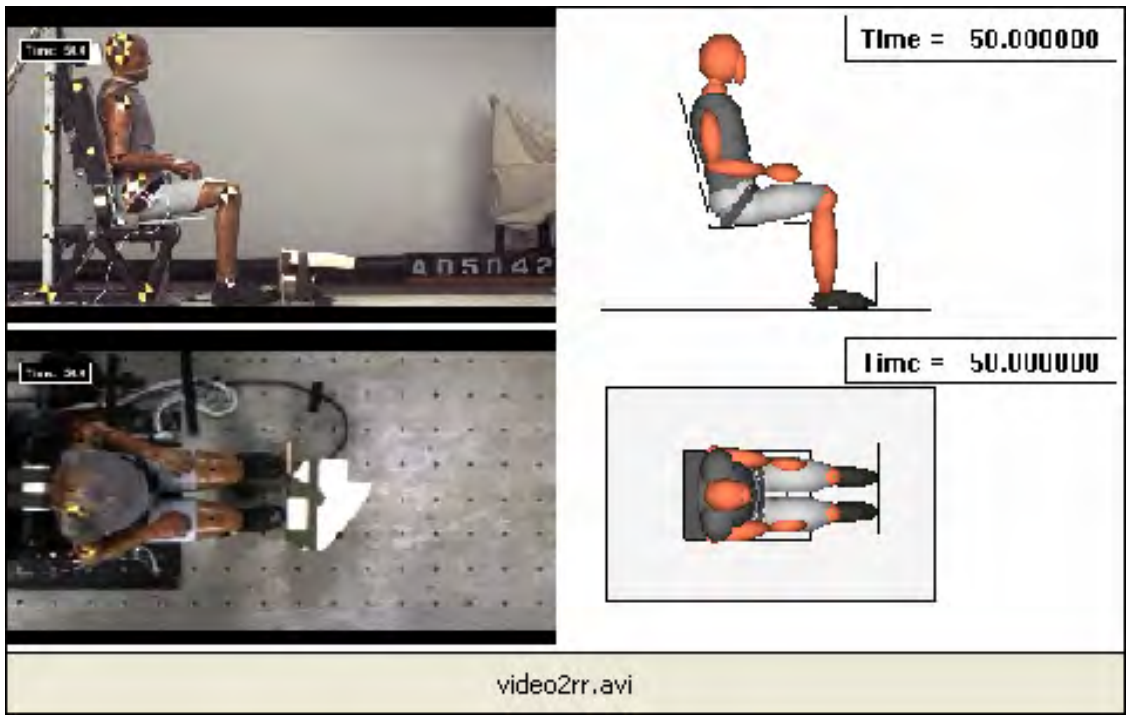




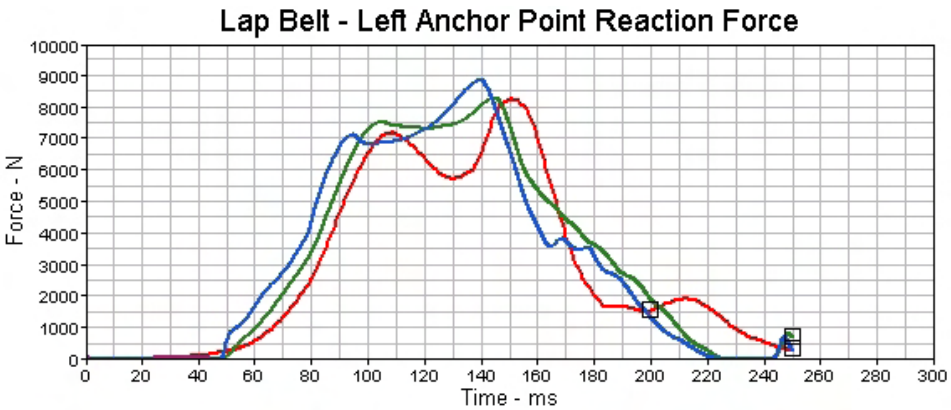


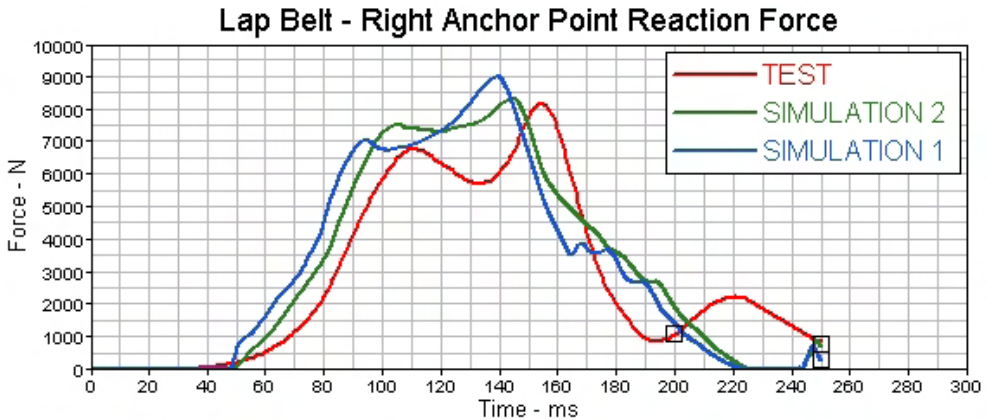


Example I: Kinematics



Example I: Belt Forces





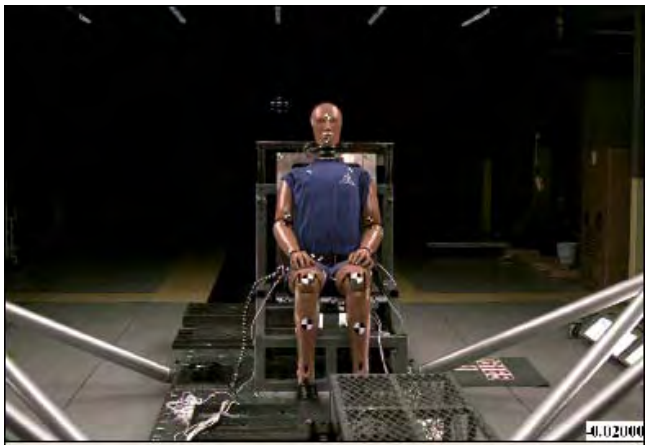
Example I: Conclusions

- The predictability of the numerical models depends on the quality of the component data
- Additional Pre-Test measurements required for setting up simulation models:
  - ATD Joint Positions w.r.t Seat Reference Frame (X,Y, and Z Coordinates)
  - Seat belt webbing material properties (Loading and Unloading Functions)
  - Webbing length measurements
  - Webbing Pre-tension Load data
  - Static and dynamic coefficients of friction for seat surfaces and webbing material
- Need to evaluate physical test variability

Test Setup – Pre-test

- 26 Targets ATD
- 9 Targets Seat
- 10 Targets Lap Belt

Test Setup - Video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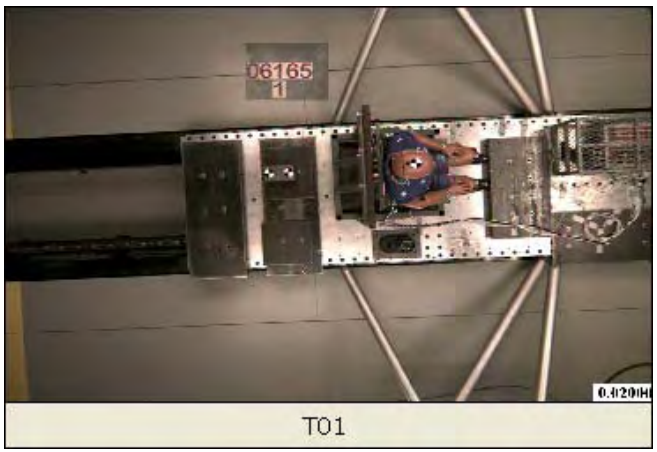
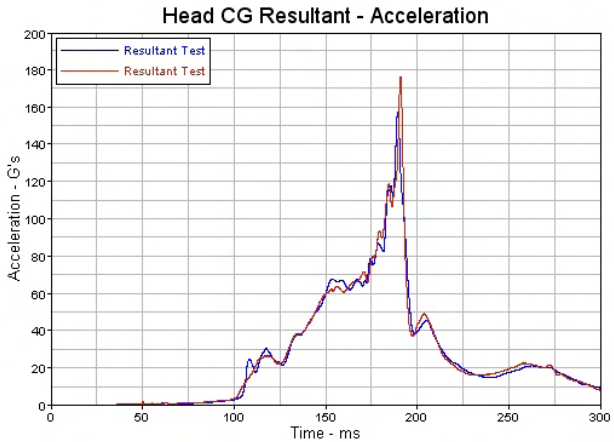
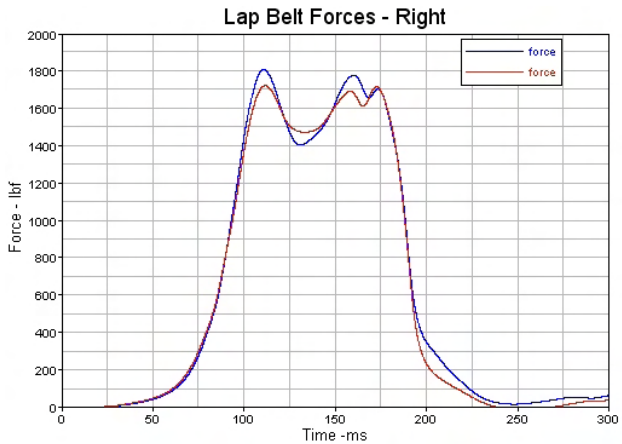
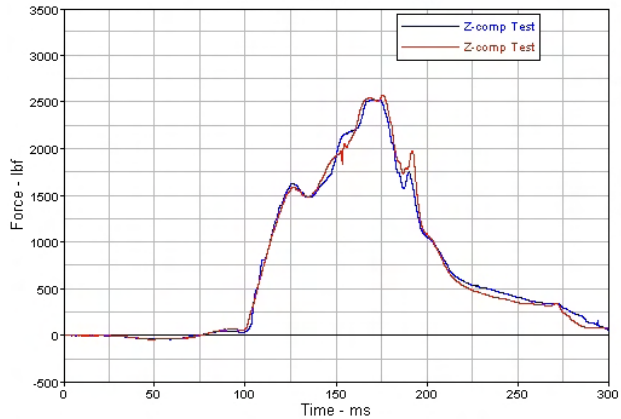

T01

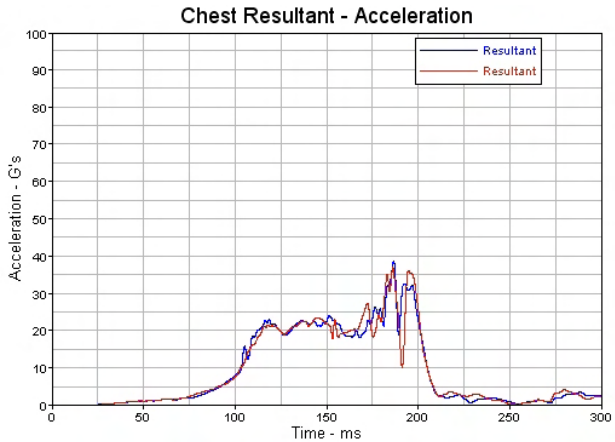

On01

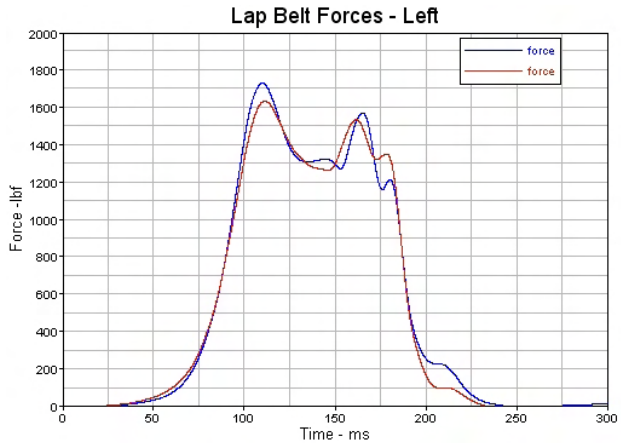
Hybrid III - Repeatability

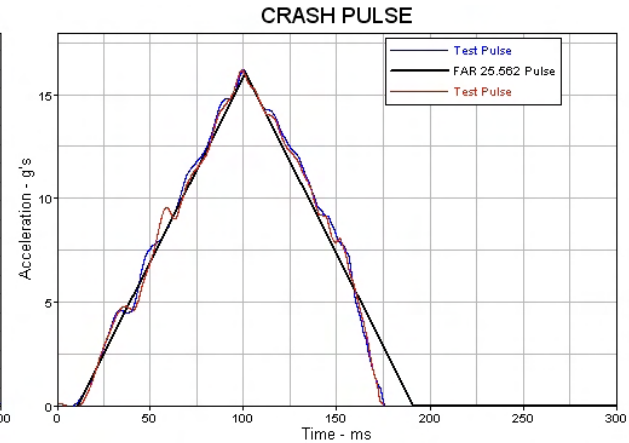




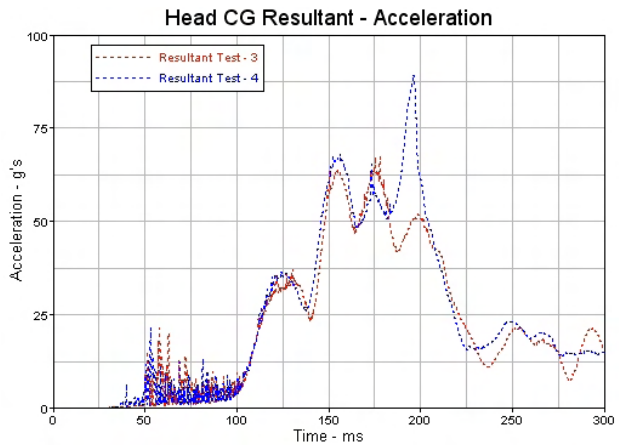


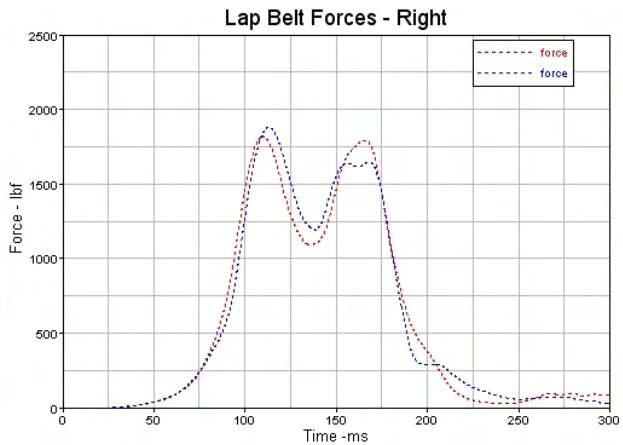


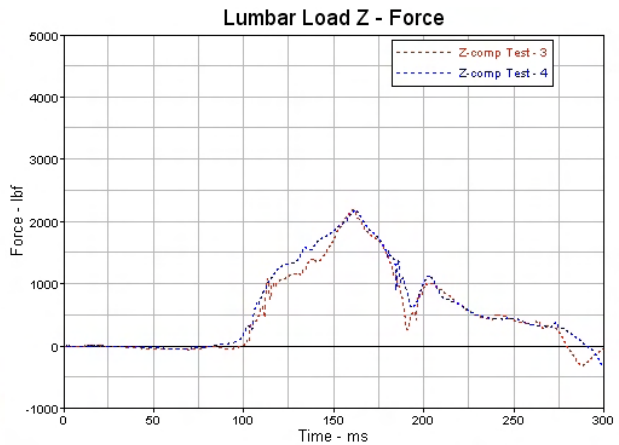


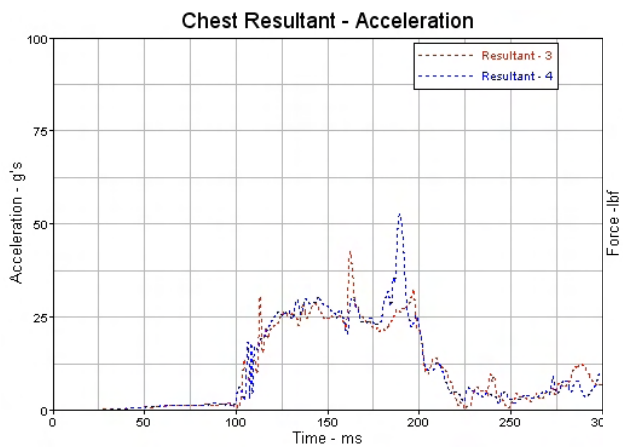


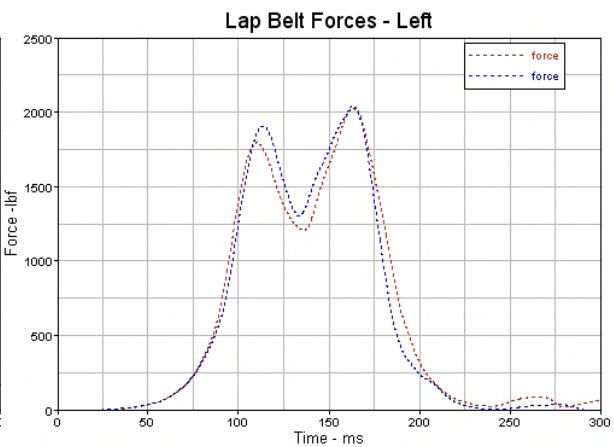
Hybrid II - Repeatability

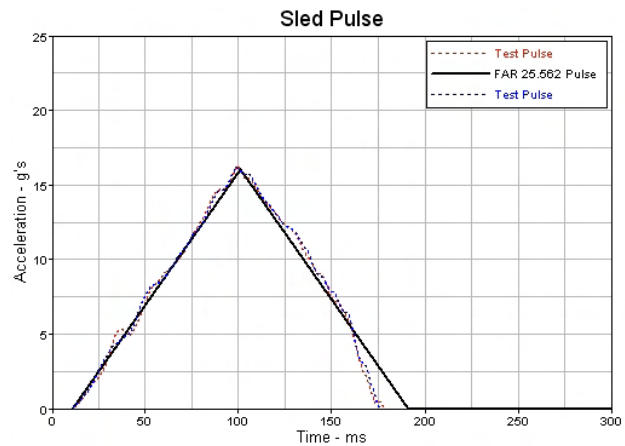












A Look Forward

- Benefit to Aviation:
  - Reduce certification costs
  - Reduce development cycles
  - Improve product design
  - Provide a simulation industry standard
- Future needs
  - Typical Seat Material Databases:
    - Strain Rate Dependency, Compression, Tension, Failure Criteria
  - Typical Joints and Fittings Modeling Guidelines:
    - Component Testing, Failure Models, Modeling Techniques